Aalto University
School of Arts, Design
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Applications of Optical Illusions in Furniture Design

Henri Judin

Master's Thesis
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and Architecture

P.O. BOX 31000, 00076 AALTO
www.aalto.fi

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Author: Henri Judin		
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Optical illusions prove that things are not always as they appear. This has inspired scientists, artists and architects throughout history. Applications of optical illusions have been used in fashion, in traffic planning and for camouflage on fabrics and vehicles. In this thesis, the author wants to examine if optical illusions could also be used as a structural element in furniture design.

The theoretical basis for this thesis is compiled by collecting data about perception, optical art, other applications, meaning and building blocks of optical illusion. This creates the base for the knowledge of the theme and the phenomenon. The examination work is done by using the method of explorative prototyping: there are no answers when starting the project, but the process consists of planning and trying different ideas until one of them is deemed to be the right one to develop. The prototypes vary from simple sketches and 3D modeling exercises to 1:1 scale models.

The author found six potential illusions and one concept was selected for further development based on criteria that were set before the work. The selected concept was used to create and develop WARP - a set of bar stools and shelves. The final objects combine the praxis of furniture design and optical illusions. They deceive the viewer, but the illusion is not only a visual effect; it also strengthens the structure. Other criteria for the final designs are its distinctiveness, newness and suitability for manufacturing.

Keywords: optical illusion, explorative prototyping, furniture design

Aalto-yliopisto
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Optiset illuusiot ovat todiste, että kaikki tässä maailmassa ei ole sitä, miltä ne saattavat ensin näyttää. Tämä on inspiroinut tiedemiehiä, taiteilijoita ja arkkitehtejä kautta aikojen. Optisia illuusioita on käytetty hyväksi niin muodissa, liikennesuunnittelussa, kuin naamiointikeinona sodassa. Tässä opinnäytetyössä selvitetään, voiko optiset illuusiot olla myös rakenteellisena osana huonekalusuunnittelussa.

Työn teoria koostuu kerättyyn tietoon havaitsemista, optisesta taiteesta, optisten illuusioiden merkityksestä, niiden käyttösovelluksista ja rakentumisesta. Tämä luo tietopohjan ko. aiheelle ja ilmiölle. Tutkimustyö toteutetaan käyttäen *tutkivan koemallintamisen* (explorative prototyping) keinoja: Työn alkaessa ei ole vastauksia, vaan erilaisia ideoita suunnitellaan ja kokeillaan, kunnes löydetään yksi, joka vaikuttaa oikealta jatkokehitettäväksi. Prototyypit vaihtelevat yksinkertaisista luonnoksista ja 3D-mallinnuksista kokonaisiin 1:1 malleihin.

Kuudesta illuusiosta yksi konsepti valitaan jatkokehitettäväksi perustuen työn alussa määriteltyihin kriteereihin. Valitun konseptin tuotekehityksen myötä syntyy WARP -baarijakkara ja -hylly, joissa yhdistyy käytänteet huonekalusuunnittelusta ja optisista illuusioista. Kalusteet hämäävät katsojaa, mutta illuusio ei ole vain visuaalinen efekti, vaan se lujittaa myös rakenteen. Kriteereihin kuuluu myös tuotteiden huomioarvo, uudenlaisuus ja tuotantokelpoisuus.

Avainsanat: optinen illuusio, explorative prototyping, huonekalusuunnittelu

TABLE OF CONTENTS

1. FOREWORD

On an icy winter day in 2014 I visited Victor Vasarely's (see: OP – art of science / science of art, p. 38.) exhibition *Optical Paintings* in EMMA - Espoo Museum of Modern Art, an extensive showcase of Victor Vasarely's work from 1948–1979. The exhibition was an eye-opening experience for me and probably the most significant driver for the subject of this thesis.

I have had a certain curiosity and interest in optical illusions since coming across the first one I ever remember seeing in primary school in 1997. Optical illusions have also been a major source of inspiration to me and I have exploited the principles of them in my drawings and paintings. The interest grows from the dialog between *art* and *science*. I am not an artist, but an aesthete; I am not a scientist; but a seeker. The art-science relation of optical illusions is explored more profoundly in chapter 2.3. on page 38. Incorporating optical illusions into my furniture design has been a long-time ambition of mine and has motivated me throughout the process of writing this thesis.

I also believe that optical illusions can break up the monotony of our everyday lives, as we come into contact with so much information and stimulation every day. According to a study made in 2007 by Dr. Martin Hilbert and his team at the University of Southern California, we come in contact with 174 newspapers worth of information every day (Alleyne 2011). The result is approximate, and the number is most probably even bigger in 2019. Nonetheless, 174 newspapers worth of data a day is already such an incomprehensible amount, so it is not surprising that very few things faze us anymore. We read books, watch movies, play video games, do extreme sports, go to escape rooms, museums or exhibitions to find experiences that wake us up from reality and make us feel and think. I want to incorporate this idea through my design into everyday objects. I don't want to create design that takes the viewer or the user for granted, but instead challenge them with elements of surprise and imagination in everyday moments. I think optical illusions are a perfect medium to execute this ambition. Roger Shepard (1990, 3), a Cognitive scientist and author, has almost poetically summarized my thoughts on the essential of optical illusions:

“A vague disquiet moves us to give something a closer look. We then see that what is before us is very different from what it first appeared to be. The world that we have relied on for solidity and stability shudders and shifts unpredictably, as if in a dream. Continuing our scrutiny, we finally satisfy ourselves that the aberration was only in the eye of the beholder and not, after all, in the world beheld. Reality regains its former stability and composure – and we laugh. It is the laugh that follows a narrowly averted accident.”

The outcome of this research was a part of an exhibition titled *Alestalo x Judin x Väre*, which was part of the Milan furniture fair during Milan Design week in 2019. The exhibition, the prototypes and such significant international visibility would have not been possible without the financial aid of *Alfred Kordelin foundation*, *Askon säätiö* and *Aalto University*. Thank you.

1.1. STRUCTURE OF THE THESIS

The structure of this thesis does not follow the methodological order (see 1.3. Methodology, p. 12) per se, in an effort to keep up the alternation of theory and practice interesting. Structurally, this text is split in four different main sections in which the first one (this section: *Foreword*) is an introduction to the research and work. After reading this section, the reader will have an image of the purpose of this research, they will know what methods I have used and also the reasoning behind why I have chosen to use them. I will also define and open up the terminology that is used in this thesis.

The second section - *Internal Representations of the External World* is explanatory: This section mainly covers the first methodological phase: the Theoretical basis. I have collected data on optical illusions as a phenomenon; in order to understand the phenomenon, it is necessary to know a bit about how our vision and perception work. I have sought examples and applications of optical illusions in the real world and in culture. Optical art is such an influential area in itself that I have dedicated a whole subheader to it.

The third section - *From Two Dimensional to Three Dimensional* is a report of the actual research work. Before presenting the research (3.2 What am I doing?), I introduce examples of *what has been done* (3.1): applications of optical illusions in the field of furniture and product design. The third section includes both the explorative prototyping process and details the creation of the final product. To prevent repetitiveness and the need to refer back and forth between the sections, instead of presenting the theories of the building blocks of different illusions in the second section where all the other data is detailed, I introduce them simultaneously and alternate with the experiments in the chapters 3.2.1 – 3.2.2.

In essence, I have dissected the things that make optical illusions work into separate pieces. After taking a look at my learnings, I rearranged the building blocks of optical illusions and made more profound experiments (see 1.3.2. Explorative prototyping, p. 12) with the chosen illusions using various techniques and materials, introduced more profoundly in the chapter 3.2.2. on p. 62. Finally, I combined the knowledge gained throughout all of the previous phases with the knowledge I already have about the furniture design (chapter 3.2.3. p. 82).

The fourth chapter, *Summary,* concludes the thesis and presents a synopsis of the project, my thoughts, the outcome and my learning process.

1.2 GET YOUR TERMS STRAIGHT

Firstly, we need to understand the difference between *Visual illusions* and *Optical illusions*? One of the main English dictionaries, *Oxford's online dictionary,* defines the adjective *visual* [2016] as: “Relating to seeing or sight”, whereas the first definition of *optical* [2016] in the same dictionary is defined as: “Relating to sight, especially in relation to the action of light”. Additionally, the term *optical* relates to the science of optics, the branch of physics that studies the behavior and properties of light. The American English dictionary, *Merriam-Webster's online dictionary,* includes an additional definition for the word *optical* [2016]: “Of or relating to optical art”.

Neither Oxford's nor Merriam-Webster's dictionary defines the term *Visual illusion,* but in the literature it is used interchangeably with *Optical illusion,* seemingly meaning the same thing.

Out of curiosity, I checked the number of search results for both of the terms in a Google search (24.11.2016): “Visual illusion” returned 462,000 results, whereas ”Optical illusion” returned slightly more with 597,000 results. The gap is smaller than I expected, as I already assumed that *optical* was the correct term to use when talking about the illusions of sight. Of course, this little search doesn't tell the truth which term is the correct one, as they may have been used in very different contexts.

According to Oxford's online dictionary, an *Optical illusion* [2016] is: “1: Something that deceives the eye by appearing to be other than it is. 1.1: An experience of seeming to see something which does not exist or is other than it appears.” Merriam-Webster's dictionary doesn't separately define the term *optical illusion*, but it directs to the general definition for *illusion*.

Bruno Ernst (1986, 9.), a Dutch physicist and mathematician uses a pretty similar definition to the one included in the Oxford dictionary: ”Optical illusions are things which we see but which either do not exist in reality or whose real nature is different”. But he also adds that this definition is insufficient, as the unique character of different kinds of illusions is overlooked. He separates the optical illusions that we see in our everyday life but don't pay attention to (e.g. the distance cue of retinal size, fig.1, p. 9.) from the optical illusions that possess an unusual character, which usually are named after their “inventor”, for example Zöllner illusion (fig. 43, p. 79).

Figure 1

The distance cue of retinal size: When I look out of the window, the neighboring building's window appears smaller than the keys on my desk. Yet I don't give the phenomenon a second thought. Optical illusions are for the most part an integral aspect of our perceptual expectations (Ernst 1986, 9).

Roger Shepard (1990, 3), a cognitive scientist, also separates *visual illusions* from *ambiguous figures* and *impossible objects*. By illusion he means perceptual interpretations that we find surprising and different from our environment that we are used to thinking of as the truth. Ambiguous figures are images with two or more perceptual interpretations that are mutually incompatible but only one of them can be fully experienced at a time. By impossibility he means three-dimensional objects or scenes with different parts that are incompatible with each other and therefore disallow us to perceive them as a whole (e.g. Penrose triangle, fig. 40, p.73). (Shepard 1990, 43.)

Different kinds of illusions are not totally mutually exclusive: the same elements, either the use of fundamental geometric shapes in a particular way or perceptual delusion, most often the combination of them, seem to be the building blocks for all visual illusions (3.2.1 The Building blocks, p. 52). But to create a better understanding, it is important to categorize and name the different phenomena. In this thesis, I call the general phenomenon of all the illusions of sight (including the natural illusions) *Visual illusions* and more specific illusions, such as Reversible Images (p. 64), Zöllner illusion or Moiré patterns (p. 71), *Optical illusions*. Unlike Shepard, I also count ambiguous figures and impossible objects in this category.

While I focus on Optical illusions in this thesis, it is also important to understand the essence of visual illusions and the fundamentals of perception as wider phenomena as well, which are briefly explained in the chapter 2.1, page 22. After all, more than fully understand the complicated process of what happens in our eye and brain when viewing optical illusions, I am more interested in knowing why we are able to see optical illusions and the meanings and possible applications of them.

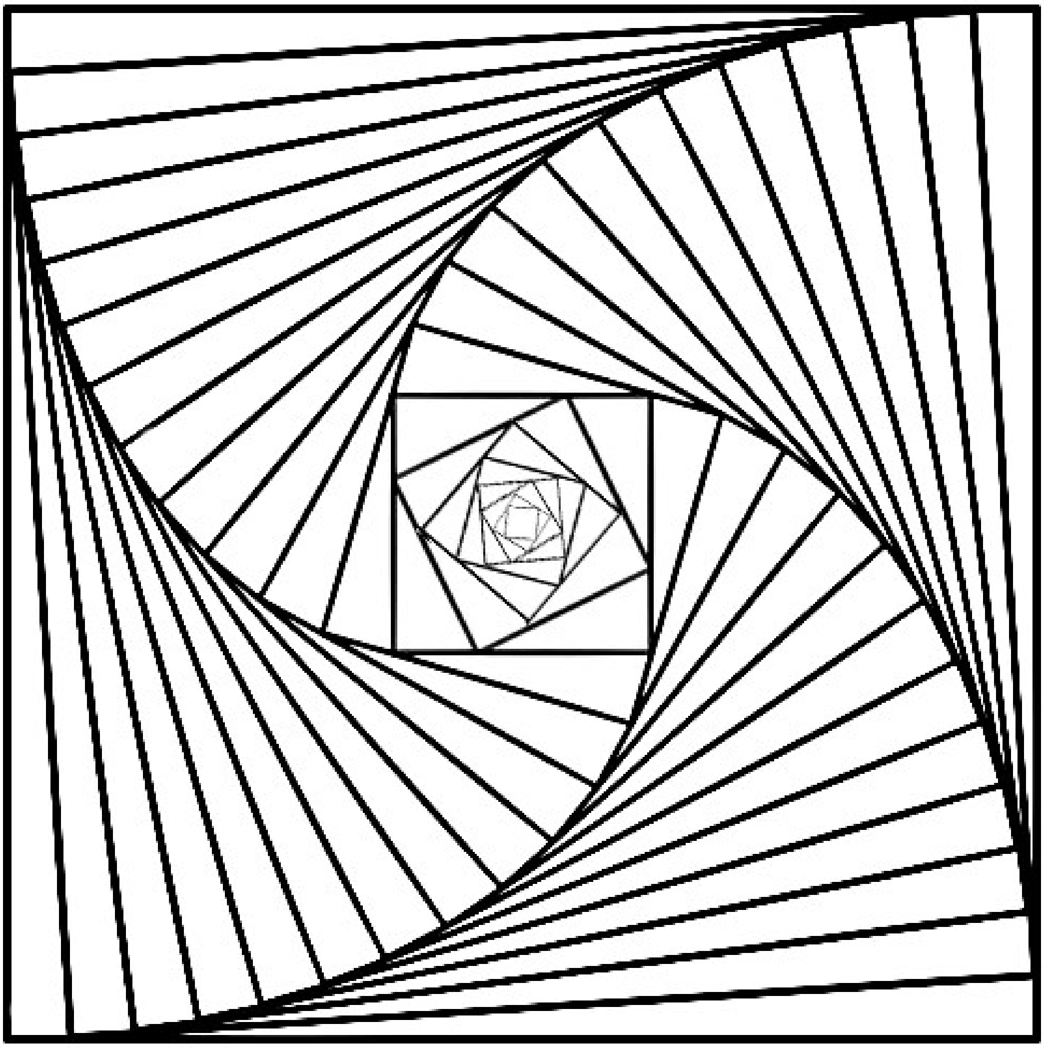


Figure 2

The alternation of technical, practical, critical and intuitive interest of knowledge. The image is made based on Jürgen Habermas's and Pirkko Anttila's studies of the Interests of Human Knowledge.

1.3. METHODOLOGY

As mentioned, this thesis is split into three parts: 1) Theoretical basis, 2) Explorative prototyping and 3) Creating. Based on Jürgen Habermas's (1972) and Pirkko Anttila's studies of the human knowledge interests (Fig.2, p. 11.), the main interests of this thesis are in technical and intuitive knowledge. The importance of them alternates in the different phases. The interests of knowledge, approach, methods used and the data pursued in the three different methodological phases are all described in stages below and visualized in the chart (Appendix 1).

1.3.1 THEORETICAL BASIS

The first part of the thesis is *descriptive*: The aim is to explain and discover the fundamental pieces and characteristics of the phenomenon called *optical illusions*. The interest of knowledge is *technical*; I have collected existing research about optical illusions, op art, science, meaning and mathematics that cause optical illusions, perception (reality and delusions) and behavior of the eye and brain. I have also done a brief benchmark and analysis of the existing products and studies from the same field. The theoretical research inspects these questions through literature, inspiring projects, people, images, products and exhibitions. This builds the knowledge base of the thesis in which I refer to in the examination section (3.2.2, p.62).

1.3.2 EXPLORATIVE PROTOTYPING

The approach to the second part of my thesis is *explorative*. The interest is in the interaction of *technical* and *intuitive* knowledge. The process combines experimental investigation with the data collected in phase one, creating a deeper understanding on the phenomenon of optical illusions.

In order to gain a better understanding of optical illusions in practice, I knew that I needed to experiment with different kinds of optical illusion in 'real life'. The experimental method that utilizes "informal" procedures and outcomes, and which is also used to design and develop a system or a product, can be referred to as *explorative prototyping.* This process consists of planning and trying different designs until one of them seems to be a viable option to develop further (Rouse 2006; UPEDU 2014).

During the process, I started questioning what I could and could not call a prototype. Could I call small experiments prototypes? One definition of a prototype was mentioned in many sources: “Any entity exhibiting at least one aspect of the product that is of interest of the development can be viewed as a prototype”. This definition was shaped by design research duo Ulrich & Eppinger (2012, 291). According to them, prototyping is the *process* of developing an approximation of the product, which can be in various forms, such as sketches, mathematical models, simulations, test components or even a fully functional version of the product (Ulrich & Eppinger 2012, 291). After discovering this definition, I negligently used different materials and techniques in my experimentation depending on the suitability for the examination in question. There is no point in building a one-to-one prototype in all cases, whereas in others, a sketch or a 3D model is not enough. The techniques used in my research are explained more thoroughly in the chapter 3.2.2, p. 62, which is the documentation and report of the experimentation.

The methods of explorative prototyping are commonly used in software engineering, but also in hardware development or industrial design research projects, examining the function of a product or a specific part (Rouse 2006; UPEDU 2014). The method is provably used in other kinds of projects as well: Strategic & Industrial Designer Jukka Itälä (2014) has used the methods of explorative prototyping for materials research in his Master’s thesis “*How design can contribute to materials research - Explorative prototyping as a method for collaboration between design and materials science*”. In his thesis, he has used the methods in a simple, descriptive and productive way and through his case studies he proves that explorative prototyping supported his materials research process. By prototyping in an early stage of a product development process, he could separate the solutions that could directly be brought forth from the ones that had problems to be solved before production. Even when he pre-defined solutions to be tested, the methods of explorative prototyping often revealed new and unexpected information. Therefore, explorative prototyping is a useful tool for diverse applications and I also found it a suitable method for my purposes. (Itälä 2014, 130.)

The Unified Process for Education, UPEDU (2014), a web publication of software engineering practices by *Polytechnique Montreal,* defines the features of explorative prototyping in more detail as experiments to test a key assumption about the project. These features can be related either in functionality and technology of a software or a hardware component, or both. It is also a way of clarifying requirements and preventing large-scale failures in a later phase of the project. (UPEDU 2014.)

The definition of explorative prototyping by Gengnagel, Nagy & Stark (2016, 92-95) caught my attention because of its interesting use that is not purely for software development. They include explorative prototyping as a part of *hybrid prototyping* methods used in the development of product-service systems. This can mean, for example, combining intangible services and tangible objects into an integrated system, or when the research is about combining physical prototypes and digital models in a Virtual Reality environment. For example, they state that, in architecture, the methods of hybrid prototyping and explorative prototyping are valid as such, as all interfaces that affect objects, environment and infrastructure can be called hybrids. (Gengnagel, Nagy & Stark 2016, 92-95.)

UPEDU (2014) has categorized prototyping into two different main groups by the information they can provide: In the first group, "what they explore", there are two kinds of prototypes: *a behavioral prototype*, which focuses on exploring a specific behavior of the system; and *a structural prototype*, which explores constructive, architectural or technological concerns. There usually is a concrete outcome in the prototypes of the second group are. Exploratory prototype belongs to the second group along with what they call *an evolutionary prototype*, which gradually develops to become the real system.

Explorative Prototyping Process

What is the difference between a "normal" prototype and an explorative prototype? According to Margaret Rouse (2006), a writer and manager of *WhatIs.com*, *TechTarget's encyclopedia and* one of the major publications of the IT industry, the difference is in the process; explorative prototyping begins at a more nebulous starting point, and proceeds in a less formal way. The downsides of this method are that it is not particularly cost-effective and as the result is unknown, it may sometimes lead to an undesirable outcome.

James Ford (2016) has summarized three simple and straightforward steps for explorative prototyping. He has uncovered these points through his own experimental work, so I regard the information rather 'informal' yet very rational. As the procedure is relatable to this project, I have decided to adopt his discovery into account and examine them in practice.

According to Ford (2016), the three essential steps for explorative prototyping are:

1) Understand the key goals
2) Maintain a narrow scope
3) Set a short timeframe

To be able to have a successful explorative prototyping process, it is crucial to setgoals. The examiner needs to know '*why'* they are doing the work, to have a challenge and a reason. There also needs to be an idea of '*how'* to begin to work towards achieving the goal. Both need to be known before beginning. Sometimes, there only might be a type of technology that the examiner wants to explore (the *how*), but a prototype without a reason (the *why*) will turn into a simple proof of a concept application. A challenge (the *why*) without any idea of a solution (the *how*) is not ready to begin working on yet. (Ford 2016.)

Additionally, there are goals with different levels of importance. There should be only one high-level primary goal and a few secondary goals. Some of the secondary goals might change or must be sacrificed during the development process to limit the scope or to keep within the time limit. (Ford 2016.)

As claimed by Ford, the explorative prototyping project is more fruitful when the work is limited to conceptual level. This way it is possible to explore more features in a shorter time. It is often easy to get lost in all the opportunities when the high-level goal could be solved in many of different ways. But if there are many experiments going on at the same time, or if the experiments are too profound, there is a risk of *scope creep*: an uncontrolled growth of the project, when the level of complexity increases while the time to accomplish the project exponentially decreases. To prevent this, Ford advises to refine and list the goals, focus on a single feature at a time, deliver a final feature, and only then move on to the next one. (Ford 2016.)

Finally, for a successful explorative prototyping process, there needs to be a timeframe. This can vary depending on the project, but Ford (2016) recommends a short timeframe and prefers to limit his timeframe measured in hours, not days or weeks. A prototype is a proof of concept, so it doesn't need to be beautiful, but it needs to work (or not) and accordingly make some measurable progress towards the initial goals. The timeframe should be long enough to be able to estimate the time it takes to finish the actual version. If the set time is not enough to achieve the desired result, it means that the examination might be too complicated, and one should reconsider how to simplify it.

Rouse (2006) specifies that the method works best in situations where only a few, or none, of the requirements of the final system or the product are known in detail beforehand. She has created a basic model for the explorative prototyping process:

- → The starting point is crucial for the work: All the information available is gathered together to get an idea of what the new system will be, how it is expected to work, and how it can be done.

- → A system is put together, based on the gathered information and the ideas formulated in the first step

- → The system is tested to see how it performs and how to improve it

- → A second-generation system is developed from the first one, based on the improvements proposed in the previous step

- → The second system is tested, as was the first. Its performance is evaluated, and possible improvements determined

Exploratory prototypes can be intentionally done in a "throw-away" fashion and the process can be performed once or repeated as many times as necessary to obtain user satisfaction – or until it is decided that the project is unworkable. (Rouse 2006; UPEDU 2014.)

When observing the categorizations and the process of explorative prototyping above, one needs to keep in mind that the method was initially created for a software development. Regardless, I adopted the method for this research because of all the similar features and objectives: the end result of the research is unknown, I want to test as many different illusions as possible, and limit the work to a conceptual level. In this part I am planning to achieve quantity rather than quality so that I have a lot of material to choose from for the final object(s). Building a lot of prototypes is also an exciting way to explore something new and take chances in the design process that I normally wouldn't try. It is also an opportunity to refine my handworking and product development skills.

Heuristic technique

The method of explorative prototyping is claimed to be informal and the conclusions to be based on emotions (UPEDU 2014), rather than empirical evidence. So can the outcome of explorative prototyping be taken as valid research?

I claim that explorative prototyping as a research method can be taken as seriously as any other *heuristic* research method. First of all, the character of this research is heuristic, meaning the focus is in discovering and finding. Heuristic methods are processes where one discovers things themselves and learns from their own experiences. Heuristics believe that the deepest knowledge can be found in the individuals through their senses, perceptions, beliefs, and judgments. Heuristic researchers also develop methods and procedures for further investigation and analysis, which leads to new knowledge and information, while understanding the phenomenon with increasing depth. Even if the heuristic process can be said to be autobiographic, with every question that matters on a personal level there is always a social, and, perhaps also a universal, significance. (Moustakas 1990, 9 - 13, 15.) This is the strength of a heuristic research.

The heuristic techniques are fundamental features of knowledge seeking and understanding, such as *intuition*, *trial & error*, *indwelling*, *focusing*, *tacit knowledge* and *Internal Frame of Reference* (Moustakas 1990, 20 - 27; heuristic 2018), which are all present in my explorative prototyping process.

Intuition is an important means for seeking knowledge. It is an internal capacity to make conclusions and compose new information from existing structures and dynamics. The intuitive process goes from perceiving through observing, finding patterns, and imagining, to creating the truth. Intuition makes immediate knowledge possible without any deeper reasoning or logic. (Moustakas 1990, 23.)

A tree can be viewed from many different angles: sides, front, and back; but if you can't see a whole tree it must be intuited from the clues that are provided by observation, experience, and connecting the parts of the tree into patterns and relationships that ultimately enable an intuitive knowing of the tree as a whole. (Figure 3.)

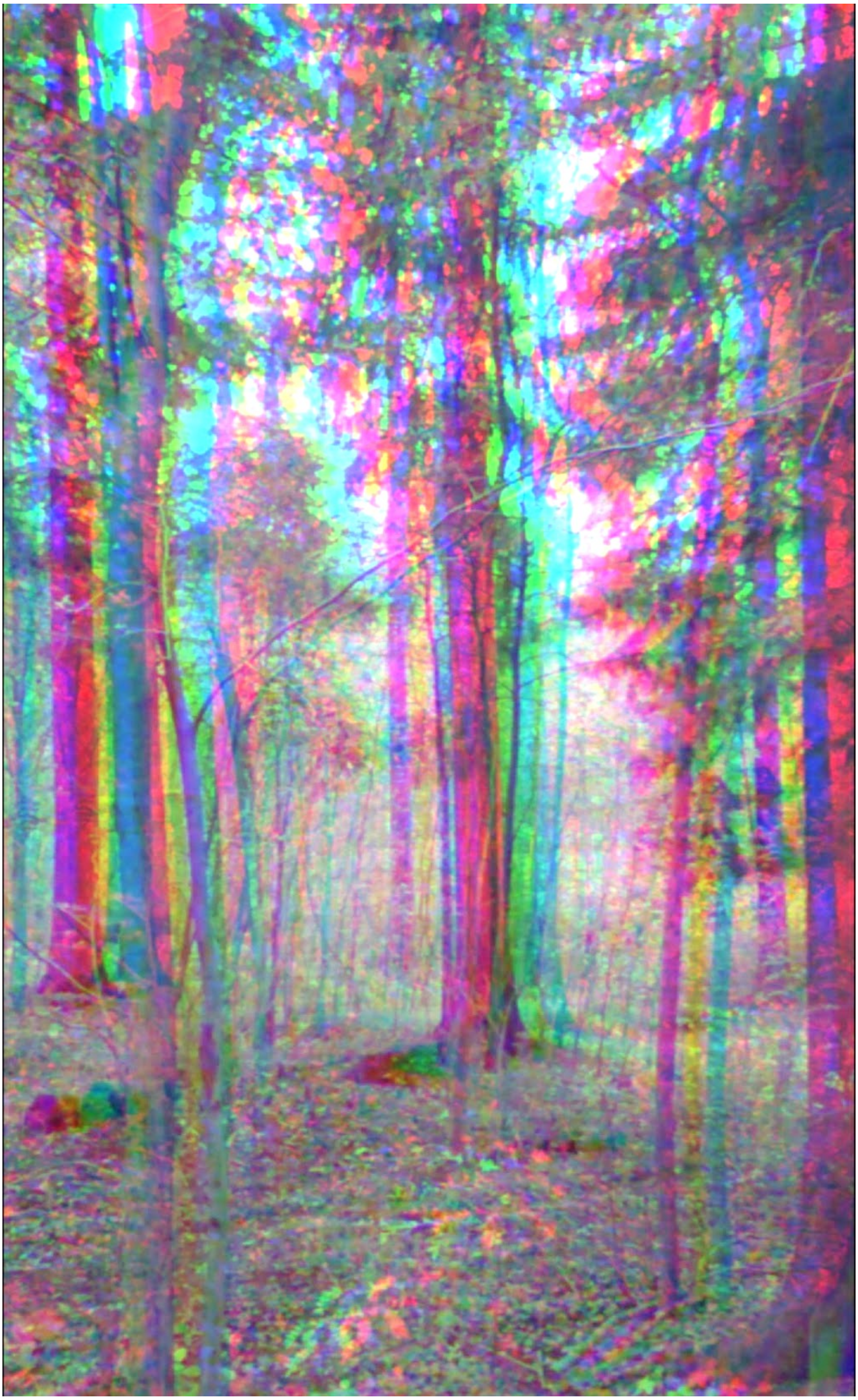


Figure 3

A technique where one tries out one or more ways to find out the best way to reach a desired result or a correct solution by observing and eliminating errors or causes of failure is called *Trial and Error*. The objective of trial and error is to obtain new knowledge. The method is solution-oriented, so *why* a solution works or doesn't work is not meaningful, what matters is that there *is* a solution. In my work, if the attempted illusion doesn't work, I do not analyze the cause of a failure further because there simply is no need for a deeper failure analysis in the Heuristic method. (trial and error 2018.)

Indwelling is the conscious process of turning inward to seek a deeper, more extended comprehension of the nature and meaning of the theme in question. Indwelling as a technique requires patience and repetition; one needs to return to the same subject again and again to be able to find its every possible nuance, texture, fact, and meaning. The indwelling process is intentional but not linear or logical, (Moustakas 1990, 24.) as it is a reflective process.

Focusing is means of turning your attention inwardand pausing to examine the experience of a phenomenon. Focusing enables one to see the phenomenon as it is and to separate the irrelevant information from the necessary. Through the focusing process, one is able to define core themes and achieve more clarified knowledge about a subject. (Moustakas 1990, 25.)

Tacit knowledge is a concept created by a Hungarian medical scientist and a philosopher *Michael Polanyi* (1891–1976). Tacit knowledge is non-conceptual knowledge that people use unconsciously and instinctively. It is so called "subsurface" knowledge or "hidden truth" that cannot be shaped or externalized. Koivunen (1977, 77), basing her method on Polanyi (1983,4) explains tacit knowledge to be the base of all knowledge: a person always knows more than they are able to tell or describe. For example, it is the skill of our hands, the feeling in our skin and the knowledge of the deepest layers of our brain that tells us when a dough is perfectly mixed. Tacit knowledge is gained through imitating, identifying and repeating. (Koivunen 1997, 78–79, 84.)

It doesn't matter if the knowledge is gained and deepened through tacit, intuitive, indwelling, trial & error or focusing techniques, its base is always in *the Internal Frame of Reference.* This means that every human experience is dependent on the person who has had the experience. Only they can validly provide descriptions of the experience through their perceptions, thoughts, feelings and senses. (Moustakas 1990, 26.)

1.3.3 CREATION

The approach to the third methodological part of this thesis is *explanatory*: this part introduces the actual design work where I combine the gained knowledge of the previous phases with my personal expression of the phenomenon and the knowledge I already have about furniture design. The process is not as strictly framed as in the previous phase. I know the technique, but in the beginning of this phase end result is unknown. The final knowledge and the end result is: ***a piece or a series of furniture or object which demonstrates a strong understanding of optical illusion in the structure and proves that we can't always believe in our senses.***

The interest of knowledge is *intuitive*. The final knowledge comes from my own subjective insights, feelings and experiences. It is a combination of science and the art of discovering and inventing. Documentation is an essential part of the process and the result.

2. INTERNAL REPRESENTATIONS OF THE EXTERNAL WORLD

What are optical illusions as a phenomenon? Why and how do we perceive optical illusions? Do they have a meaning or are they just fun tricks for our eyes? What happens when the interface of reality and delusion meet, when we can't trust our senses, when the world is not how we assume it to be? The field of art has adopted these themes and methods since long ago (see chapter 2.3, p. 38.), but are they also utilized somewhere else?

2.1 ABC of perception

As stated before, the word “optical” refers to *sight* and *seeing* (see 1.2, p. 8), so naturally behavior of the eye is in the key element in understanding optical illusions.

In simple terms, the eye is a spherical shaped visual sense organ. Its front is transparent, while over almost eighty percent of the remaining surface is opaque. In the back of the inner surface the optic nerve spreads to form the retina, where the images are “projected”. The space in between is a series of transparent liquids and solids such as the lens, which is used for focusing the image by adapting the thickness and shape by certain muscles. The iris is a shutter in front of the lens that controls the amount of light that reaches the retina. (Luckiesh 1965, 14-15; fig. 4.)

The eye itself doesn’t see or perceive anything; sight and perception are a complex collaboration between the eye and the brain. In some cases, however, the eye and its behavior are solely responsible for seeing illusions. For example, the shape of the lens causes that the outermost straight lines in our sight tend to bend a bit. Also, in the retina, there are light-sensitive cone and rod cells, of which the latter function only under very low illumination. The distribution of these two cells is not homogenous in the eye, which is a reason for some illusions. Rod and cone cells enable seeing things like *after-images*, which are visual illusions when one stares at an object for a designated amount of time and the stimuli continues to appear in one's vision even after the exposure of the original image has disappeared. (Luckiesh 1965, 13-28; Wade 1982, 100.)

The sense of sight is different from most of the other senses because there is no direct contact with the sensation. The sense of touch involves solid contact, taste requires liquid contact, and the sense of smell requires gaseous contact. In hearing and sight the contact is indirect; hearing is based on the contact between vibrations in the air (usually) and our ears. Seeing is basically contact between electromagnetic waves (=light) and our eyes. In both cases, there are specialized nerves to intensify and to define the sensation, but the eye is such a developed instrument that we don’t only see light, but we see objects. (Luckiesh 1965, 29.)

Our vision is binocular, which means we have two eyes that are able to create a single three-dimensional image of our surroundings. The continuous movement of our eyes is also a highly complex function which, together with binocularity, is the main reason why we can perceive distance, perspective, size and form by sensing the variations of things like clearness, brightness, color, angles, movement or proportions. (Luckiesh 1965, 29-37.)

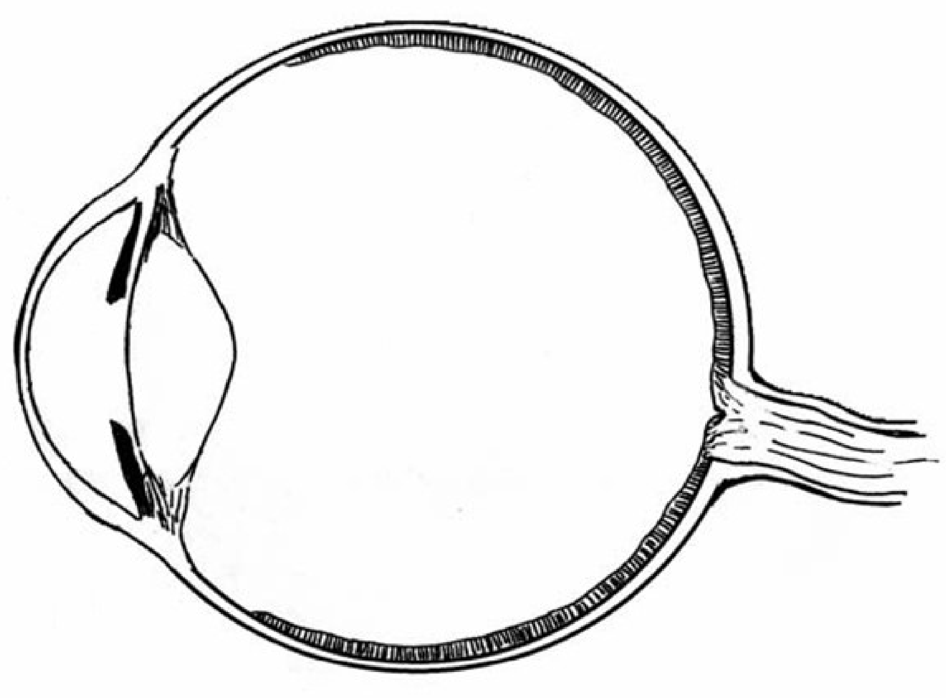


Figure 4 Eye

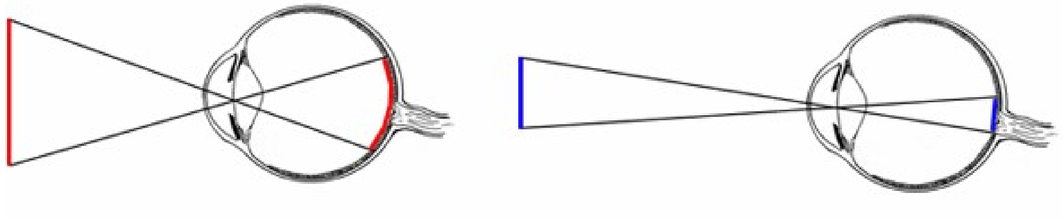


Figure 5 *The visual angle is bigger when we observe near objects (red) and becomes smaller with distant objects (blue).*

The ability to understand the distance of the neighbor's window and my keys presented in the chapter 1.2. on p. 9 is based on the basic fact that light travels in straight lines. If we think of the retina of our eye as the base of an isosceles triangle (fig. 5) and the vertex point as the object of inspection, the angle of the vertex becomes smaller the farther it moves from the base (of fixed length). That is to say, the more distant the object is, the smaller the visual angle subtended at the eye is as well. (Shepard 1990, 5 – 6)

Our eye, just like a camera or a painter's brush, captures an image of the world. This image is a flat projection of our three-dimensional world and it's impossible to compress three dimensions into two without losing some information. (Gregory 1970, 33; Rock 1984, 1-9.)

An image can also be perceived in an endless amount of ways. Our eyes are the connecting link between visual perception and objective reality, but a perception of an image is not necessarily the same as perception of the three-dimensional world. There is a philosophical term, *naive realism,* which refers to the presumption that our preceptions are direct recordings of the world around us. How we perceive the world is also very different from how other organisms do. Bees, for example, respond to frequencies of light to which we do not. Fish respond to odors and sound frequencies that are not part of our perceptual reality. This means our "reality" is very different from those species. (Gregory 1970, 33; Luckiesh 1965, 13; Rock 1984, 1-9.)

Knowing all of this, why wouldn't we assume that colors are just *surfaces reflecting electromagnetic waves of different frequencies* or smells are just *different chemical compounds*? Even if our perceptions are only mental constructions, rather than direct recordings, of the world, they are *veridical*. We can only perceive the world directly through our senses that correspond with the properties of the world around us. In a way, our perceptions of the world are *correct*. (Rock 1984, 1-9.)

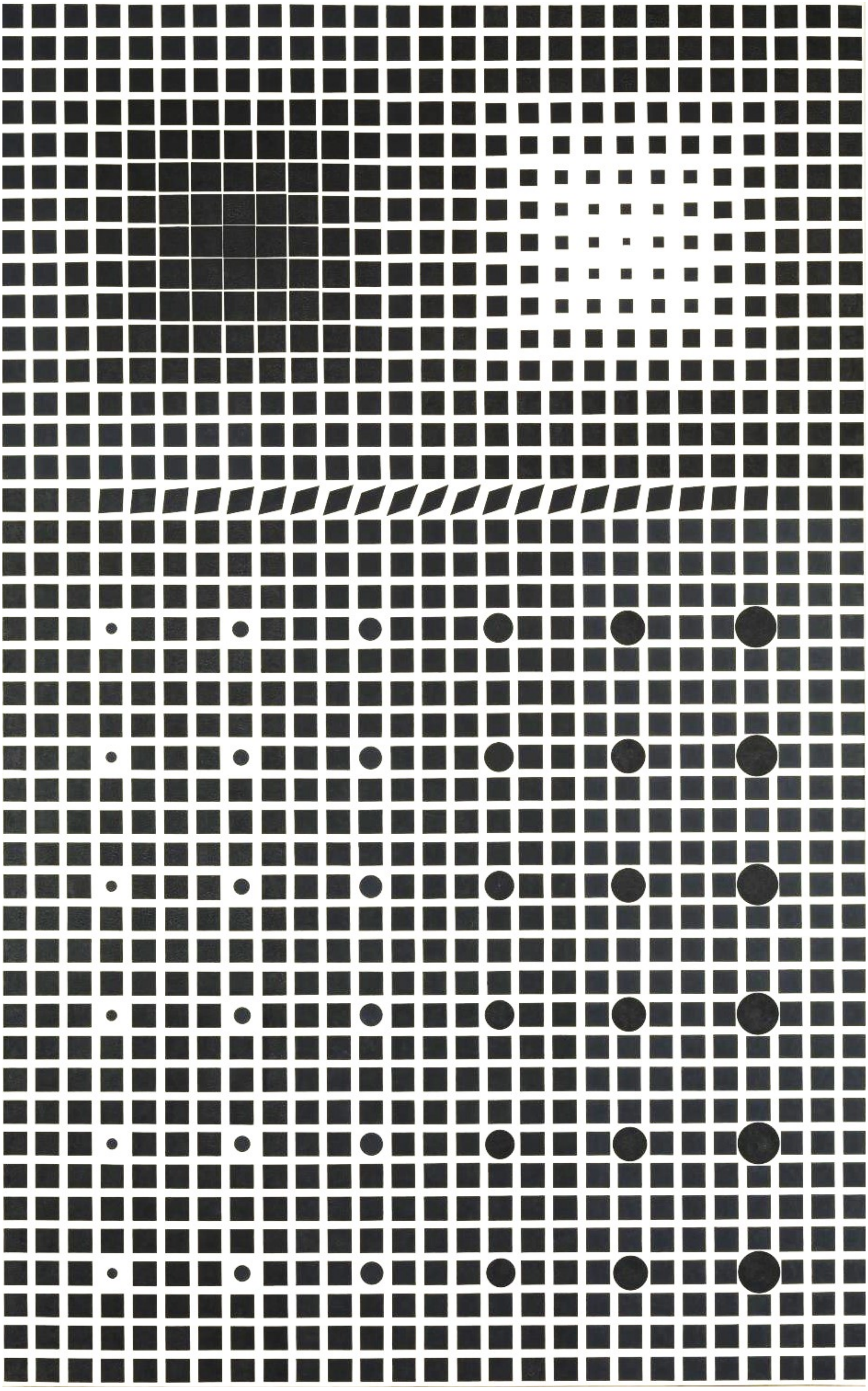


Figure 6 *“There is something positively irritating about such images” - Bruno Ernst*

2.2 Meaning and applications

Look at the Supernovae (1959-1961) by Victor Vasarely on previous page 25. Isn’t it crazy how the image plays with your mind? But optical illusions are more than just a bit of fun. In his talk ‘*Optical illusions show how we see’,* scientist Beau Lotto (2009) explains the importance and meaning of visual illusions in the research of our mind and behavior. As stated before, we have no direct access to our physical world other than through all of our senses. Out of all of our senses, we tend to trust our eyes most. Our brain instantly processes the information our eyes receive to make sense of the world around us. The brain uses mechanisms to find patterns and relationships in information and associates those relationships with behavioral meanings from our past. This has been crucial to our evolution and simply makes it possible to interact with the world. Tricking and challenging this system can reveal aspects about how our minds work. (Lotto 2009.)

In essence, we see what we have learned to see. We don’t act so much according to what we directly sense, but by what we believe (Gregory 1970, 11): I don’t set my coffee cup on an ambiguous “white patch” in front of me, I set it on a table, which I know because of the collaboration between my eyes and my brain. Lotto (2009) claims than the sensory information about what we see is actually meaningless; it is just light that falls into our eye and can mean literally anything; *context* is everything.

In his talk, he gives an example of one of the fundamentals of sight, seeing color, which is one of the simplest things brain does (3.2.1: Color, p. 58). The object of observation, a projection from the world, has three basic factors with regards to with color: the color of the actual object, color of the background and color of illumination. If any of these factors change, it will change how we see the object, which means that the same image can have infinite amounts of possible projections. (Lotto 2009.)

Our visual system has evolved over millions of years to what it is now, which is doing its best to give us reliable and accurate information about the three-dimensional world we are living in. But the world around us keeps on developing. Does our visual system keep up with the development? Roger Shepard (1990, 5) answers my question with a color example as well: natural selection has not had time to adapt to the demands of all the technological innovations we’ve seen, such as the abnormal hues of artificial lights. We easily recognize familiar objects under the variations of natural illumination during the day, but it is easier to walk past our own car at night in a parking lot illuminated by artificial lamps. (Shepard 1990, 5)

Roger Shepard has investigated the aberrations of perception and the meanings of them with interesting methods that combine his research and his art. He is a cognitive scientist who started making drawings of optical illusions for his own entertainment and to counterbalance his more serious psychological research work. By the time he came to realize the connections between the drawings and some of the principles in his cognitive investigations. Even if his methods have been different from what Lotto claims in his talk, the outcome is very similar: Shepard summarizes his discoveries by stating that what we see is a rather limited window into the world, just a reflection of it. But it is an informative window to our mind. (Shepard 1990, 4, 212-213.)

We have all this knowledge about optical illusions by researching them, but how is this information used in real life? There are a lot of examples in all fields and lines of industry. To give a brief indea about the scope, here are a few examples below:

In Architecture & Urban planning

The temple of Parthenon in Greece is not the first, but probably the most known, example of the usage of optical illusions in architecture. Margaret Livingstone (Glassman 2008), a neurobiologist from Harvard Medical School, explains the visual tricks behind the building. As stated before, our visual system tends to bend the outermost straight lines of our sight (2.1. p. 22). The ancient Greeks realized that to construct a building that appears perfect they would have to come up with a design that tricks the eye and they invented a system of optical refinements called *forced perspective* (fig. 7, p. 28). (Glassman 2008; Fig. 8.)

Optical illusion in architecture was not used only by the ancient Greeks but has been used throughout the time and is still used today. Victor Vasarely also saw the connection between optical illusions, architecture and urban planning (see 2.3, p. 40). Some of the best examples of today's architecture and optical illusions are the buildings designed by Brazilian architect Fernando Peixoto (fig. 9, p. 29).

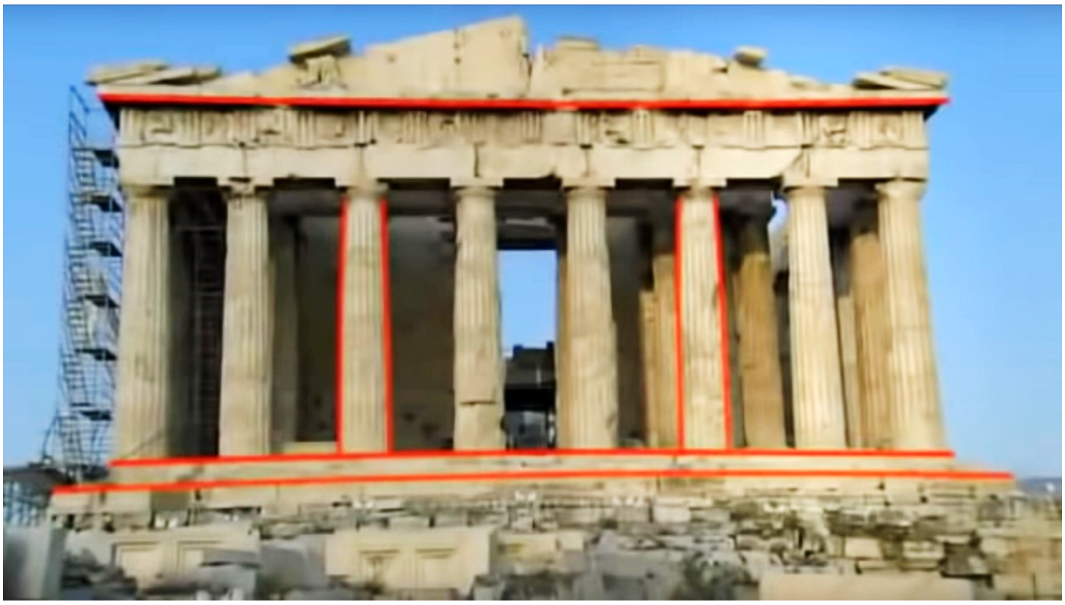


Figure 7

To compensate the illusory bending, the Parthenon temple was built with only few right angles or straight lines.

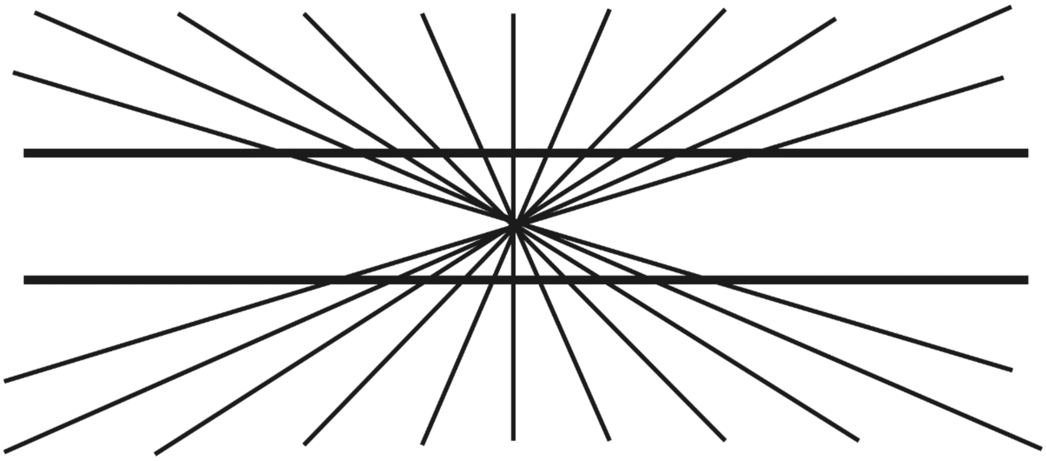


Figure 8

A phenomenon called the Hering illusion (published in 1861) is the base behind the mathematics of the Parthenon (built in 432 BC). In the Hering illusion, the straight horizontal lines seem to bend. (Glassman 2008)

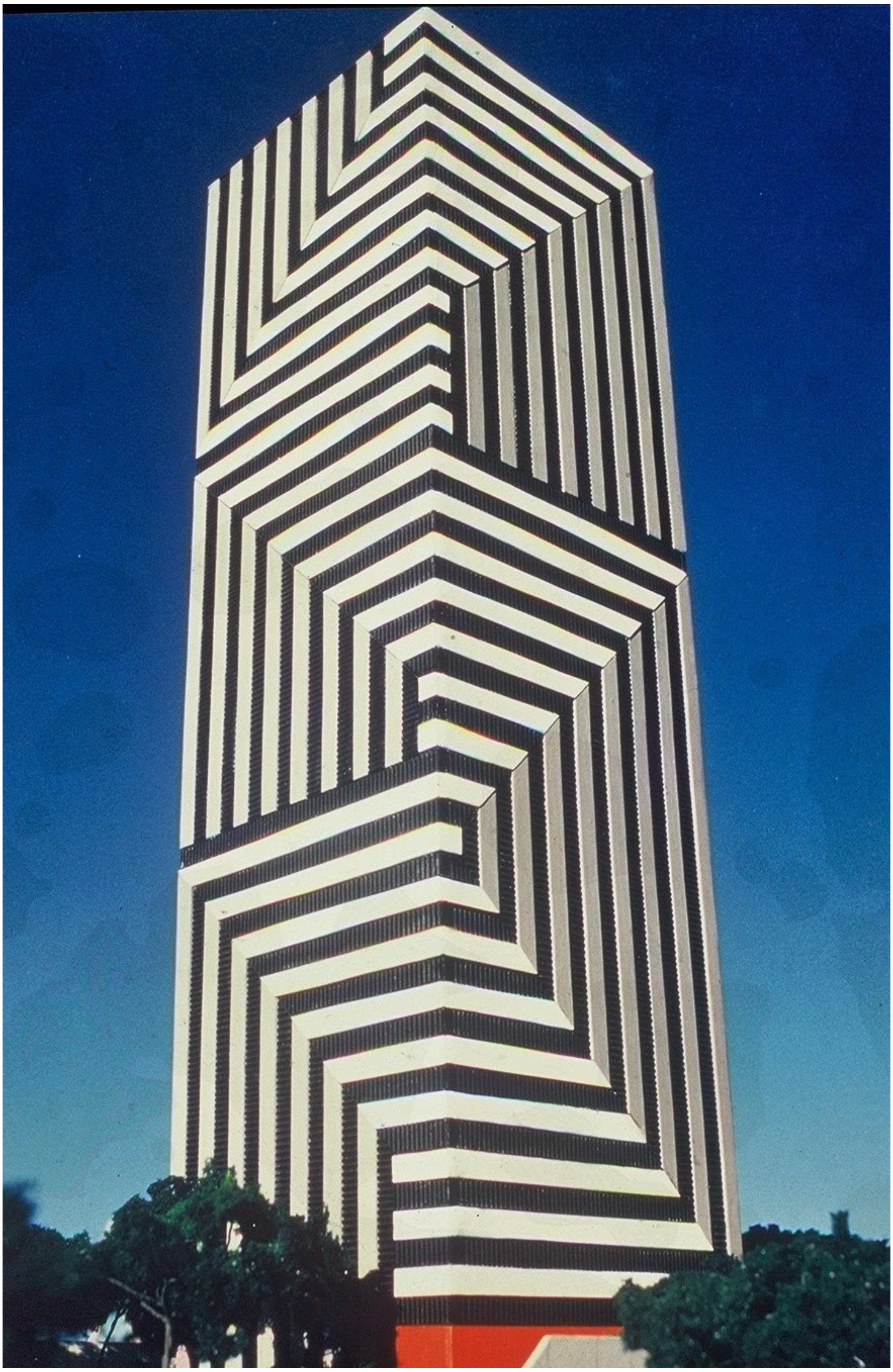


Figure 9 *A building by architect Fernando Peixoto.*

Optical illusions have also been used in interior design. Many magazines and other publications, including *Arch Daily* (2017), have noticed the floor in Casa Ceramica in Manchester (fig. 10, p. 31). Their claim that the floor is built to slow down people has actually been declined by Casa Ceramica, as their purpose was only to wow their customers and showcase what could be achieved with their products (Casa Ceramica 2017).

Either way, I believe that the use of optical illusions could be a potential way to slow people down in places where it is needed. As a matter of fact, similar methods have been used for this purpose. There are subtle and not so subtle examples: Tim Collins (2017) wrote for the Daily Mail an article about TFL's (Transport for London) trial of using optical illusions to slow down drivers on busy highways in the city to prevent death and serious injuries in traffic. They painted 45 fake speed bumps around the city, which is notably cheaper than installing the real ones. The fake bumps reduced the average speed by five km/h.

These sorts of trials work well for a limited amount of time, but people get used to them. In Chicago, officials have tried different ways of slowing down traffic at a dangerous curve on Lake Shore Drive. When straightening the curve and lowering speed limits didn't cut accidents, they tried optical illusions as a solution: by painting horizontal lines which become closer together as the driver reaches the curve, they finally reached the goal. The horizontal lines produce a visual effect similar to what your eye perceives when speeding up, which makes the driver instinctively slow down. (Moskvitch 2014; fig. 11.)

Escher (see p. 43) has amazed people through his surreal architectural images (fig. 15, p. 44.) for over a century (Escher). Kokichi Sugihara, professor from Meiji University for Advanced Study of Mathematical Sciences, claims that these kinds of impossible objects can be realized as three-dimensional objects in infinitely amount of ways. His approach to optical illusions is mathematical: impossible 2D objects are possible to recreate in three dimensions by solving equations. He explains how the optical illusion research is not only interesting, but also important to our daily lives and makes us happier. We are surrounded by optical illusions: make up, what we choose to wear, or how we take a selfie are examples of everyday optical illusions. Optical illusions cannot be removed from our brains, explains Sugihara. This is also why the example of Chicago traffic is so efficient (Meijiglobal 2017).

Figure 10 *Casa Ceramica’s entrance.*

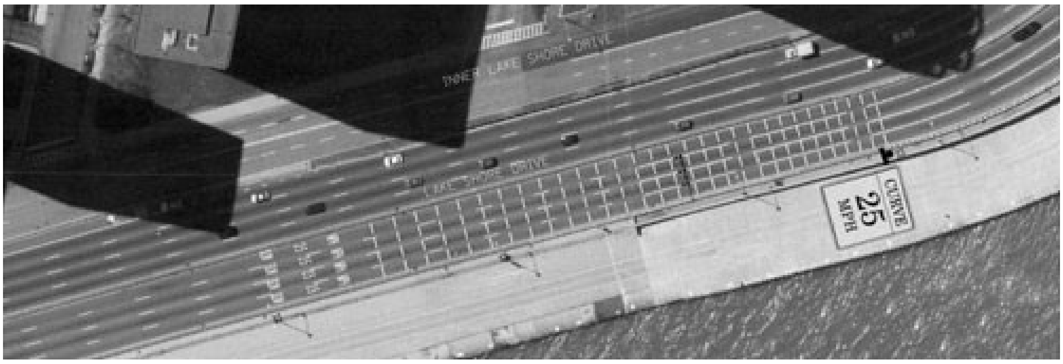
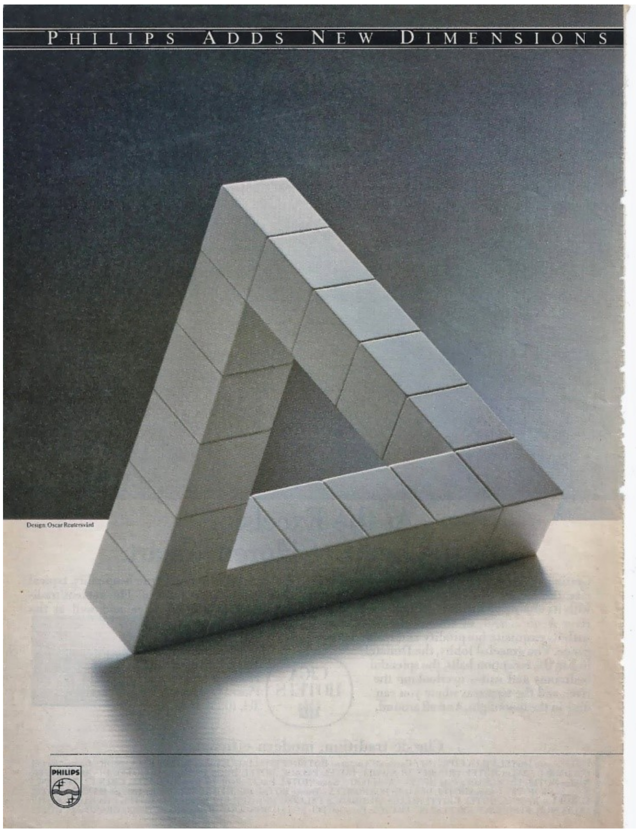


Figure 11

The horizontal lines become closer together as the driver reaches the Lake Shore Drive curve.



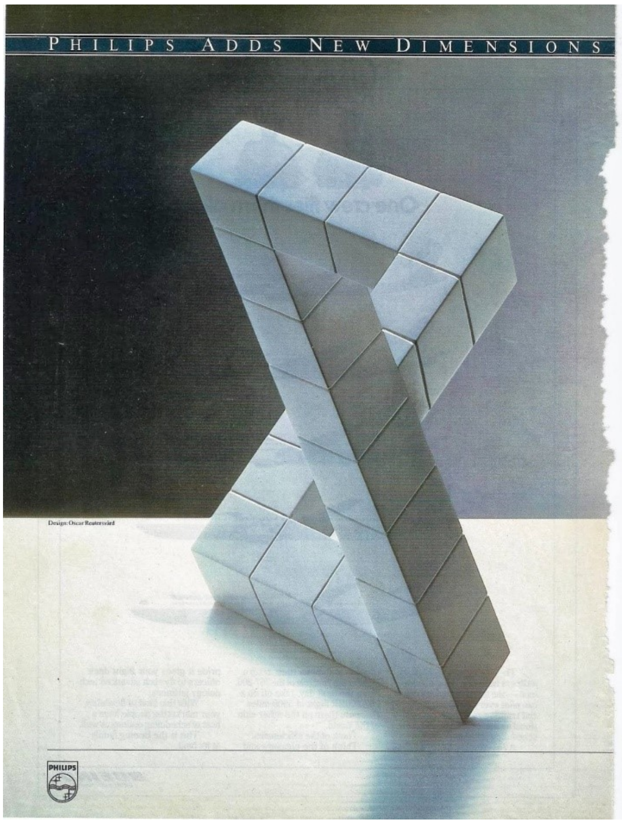


Figure 12 *Impossible objects in Philips ads from 1986.*

In Graphic design

Though graphic design is traditionally a 2D medium, there are plenty of examples of the usage of optical illusions. I wanted to find a commercial example to illustrate this point. When looking for examples, a blog post by Robin (2014) on his blog *Past Print* caught my attention. He found advertisements from Philips in *The Economist* magazine from 1986 (fig. 12, p. 32).

There are five different ads that are designed by Swede Oscar Reutersvard that present different kinds of impossible objects (see 3.2.2. p. 74). On top of each image, which are clearly photographs (which means the objects must have been built in reality), there is the text "Philips adds new dimensions". I think this is a great advertisement campaign from Philips indicating the problem-solving capacity of the company.

Dazzle camouflage

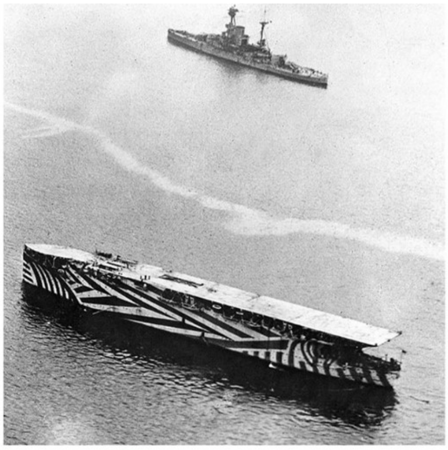
We usually understand the word *camouflage* as an attempt to create a sense of invisibility to prevent being seen. The most common way of camouflaging both in nature and among humans is so called *background matching,* which means that the patterns and colors of the target match the environment. (Scott-Samuel, Baddeley, Palmer & Cuthill 2011)

During the both World Wars, two major problems were defined and sought to be solved. Background matching only works well against one certain background but may not be effective against another. Secondly, motion breaks this kind of a camouflage. This was a problem especially in naval warfare. Dazzle camouflage was intended to disguise the size, shape, speed, range and the direction of individual boats and make individuating difficult when many boats were sailing together. (Scott-Samuel, Baddeley, Palmer & Cuthill 2011; fig. 13.)

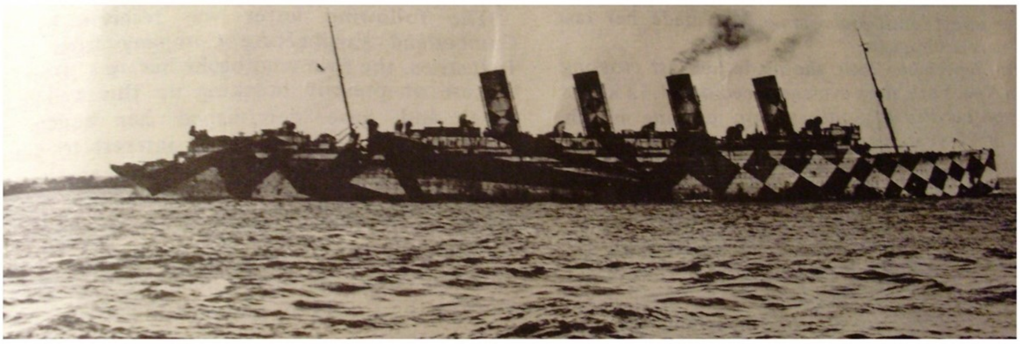
Dazzle camouflage relies on the fact that and the object is difficult to localize by distorting the appearance. Different versions were used for different purposes: for example, by applying the same pattern in different sizes on war ships, one may look further than the other. A repetitive pattern which changes its scale along the ship gives an impression that the more finely patterned end is further away than the more coarsely patterned one. In this way, the viewer could be tricked about what direction the ship was headed. Additionally, smaller objects appear to move faster than larger objects. (Scott-Samuel, Baddeley, Palmer & Cuthill 2011)

Little reliable research has been done about dazzle camouflage and its effectiveness. A research study titled "Dazzle Camouflage Affects Speed Perception" was made in 2011 by a group consisting of Scott-Samuel, Baddeley, Palmer & Cuthill. Their study focuses on speed and how it is perceived with different patterns. At slow speeds, no significant difference between the perceived speed of the patterns was noted. However, at faster speeds, high contrast patterns (such as zigzag and checked patterns) were perceived to move slower than a plain pattern. The main discovery in their research was that a dazzle pattern can distort perceived speed, if that speed is sufficiently high.

Figure 13 page 35. *Examples of dazzle camouflage used in both World Wars.*




STEWART BALE



The Best Illusion of the Year Contest

During this project, I found my community: The Neural Correlate Society (NCS). NCS is a nonprofit organization that promotes scientific research of perception and cognition. They help perception scientists, neurologists, and artists to communicate their discoveries to the public. Among other events, they host the annual *Best Illusion of the Year Contest*. The contest is open to everyone to submit a one minute video presenting their illusion. An international panel of judges rates the videos and narrows them down to the top 10 submissions. The winners are then chosen by online voters, with anyone allowed to vote once. The Top 3 winners receive cash prizes: $3,000 for first place; $2,000 for second place, and $1,000 for third place. (The Best Illusion of the Year Contest.)

I think it is great that this kind of competition exists. To me, this also means that the kind of work I'm doing is appreciated by others elsewhere. The panel of judges rates the illusions according to: significance to our understanding of the human mind and brain; simplicity of the description; sheer beauty; counterintuitive quality; and spectacularity. These criteria seem very approachable and understandable for a competition for scientific work. Therefore, I'm going to submit the end result of this thesis to the competition.

“Optical illusions can make our lives happier.”
-Kokichi Sugihara

2.3 OP – art of science / science of art

When talking about optical illusions, it is impossible to ignore *Optical art* and how it has affected us and our culture as an art movement. The purpose of Optical art is visibly different than the purpose of many other modern art movements; Optical art impresses with its visuality rather than with its themes. For me the meaning of art, in general, is that it affects the viewer. I think the strongest thing in Optical art is that when watching it, the effect is not only mental but also physical; it can actually make you feel sick! At first look the pieces might look like there cannot be any deeper meaning. But is there a message behind the hard, technical cover? Every art movement must have a reason to born. What is the justification of Optical art?

Artists have developed abstract compositions to explore a variety of optical phenomena resulting from the eye's struggle to read an image. Optical art is also called simply "Op". The term was used already in the 19th century, but was made popular by its use in a 1964 *Time* magazine article. (The Art Story Foundation 2014, Op Art.) I use both terms meaning the same thing.

Op art blossomed in the 1960's (Popper 2009). However, the first thing that comes to my mind from the art of 60's is Pop art and I am not alone in my way of thinking: according to The Art Story Foundation (2014) "Pop art has become one of the most recognizable styles of modern art". Some even argue that Op represented a kind of abstract Pop art (The Art Story Foundation 2014, Op Art). Both Pop art and Op emphasize the same kind of color palette, playfulness, graphical elements and a certain naivety. However, the brief meaning of Pop art is to create fine art from things that had become part of everyday culture: mass produced objects, music, advertisements and movies (The Art Story Foundation 2014, Pop Art), whereas the keywords of Op are more abstract, like time, motion, space and perception (Payne 2012). Op shared the field also with *Kinetic art,* which is the artist's attraction to the possibility of real motion. The question with Op was how to create an illusion of movement on a static 2D surface (see fig. 6, p. 25). (Payne 2012.)

An interesting characteristic of this movement is that these themes concerned both artists and scientists of the time. (Parola 1969, 9.) In essence, Op combines art and science. I am convinced they are not two different worlds but more like worlds that support each other. Nicholas Wade analyzes this thought in his book: *The Art and Science of Visual Illusions.* He proves a close phenomenal commonality between visual art and visual science, but he also points out the gap between the artists and the scientists: commonality has not been expressed through a common terminology. It is often difficult or even impossible to realize that the same phenomenon is discussed (Wade 1982, 263).

Wade wrote his book already in 1982, but, according to my own experience, things haven't changed much since. Still, in 2019, 37 years later, artists and scientists haven't totally found a common language. I think this has a lot to do with our compartmentalized education systems; we are taught to be proud of our own professions and everything that comes with them, e.g. traditions and terminology. This is not a bad thing per se, but I can see that, for a while, there has been a growing trend of building multidisciplinary universities, combining the existing universities, creating multidisciplinary work places and having multidisciplinary courses. Maybe this will bring the two worlds a bit closer to each other one day?

Even though scientific analysis may be applied to optical art, the Op art pieces are not always a result of scientific research. The inception of the work may also be entirely subconscious and purely a statement of the century (Parola 1969, 9). I think that is somehow the message of every artist throughout time: time and environment affect the subconscious and the subconscious creates images of the time. But what exactly was the artists of the 60's message with Op?

Op can be said to have launched in a group exhibition called *Le Mouvement* at Galerie Denise Rene, in Paris in 1955, but it was only a springboard for wider international following. The next big exhibition, *The Responsive Eye,* was held in 1965 at the Museum of Modern Art in New York. This was the point when Op caught the public's imagination and led to a craze not only for art but also for design, fashion and media incorporating Op elements. (The Art Story Foundation 2014, Op Art.)

After all, compared to the success of pop art and the way it was presented in media, the number of artists who had interest in optical effects was very marginal (Lucie-Smith 1969, 169). Art critics were never very supportive of Op either, attacking it and its effects as just tricks and gimmicky trends (The Art Story Foundation 2014, Op Art). But Op was never even meant for the responsive eyes of the critics. For a layman instead, living in a decade defined by the onward march of science, by advancements in computing, space and television, it was an easy style to relate to (The Art Story Foundation 2014, Op Art).

Probably the most known Op artist is *Victor Vasarely* (1906 – 1997), the 'father' of Op. He was born in Pécs, Hungary and he settled in Paris in 1930. It is obvious that he also was interested in science; he studied medicine for two years at the University of Budapest. Though this period of study was short for him, he adopted many scientific methods that are visible in his later work. After his medical studies, he trained in the Budapest School of Bauhaus (see 3.2.1. p. 52). (Vasarely 2004.)

During the 50's and 60's, Vasarely established and made the the aspiration of the abstract artists of the century concrete: to create a universal fine arts language understood by everyone. *Alphabet plastique* (fine arts alphabet) (fig. 14, p. 41.) is a "fine arts programming language" that consists of the basic elements of geometry like the circle, the triangle and the square and their variations which can be combined with different color scales of twenty hues each. An infinite number of variations can be achieved just by rearranging the colors or the forms defined by the artist. (Alphabet plastic; Vasarely 2004.)

But his aim was more ambitious than simply creating a matrix for artists. He envisioned an idea of his invention integrating into architecture and into our contemporary urban environment. The basic elements could be prefabricated using new breakthrough techniques and modern industrial technologies, allowing the works to become monumental pieces. Victor Vasarely himself has stated:

"The movement does not rely on composition nor on a specific subject, but on the apprehension of the act of looking, which by itself is considered as the only creator."

\- Victor Vasarely

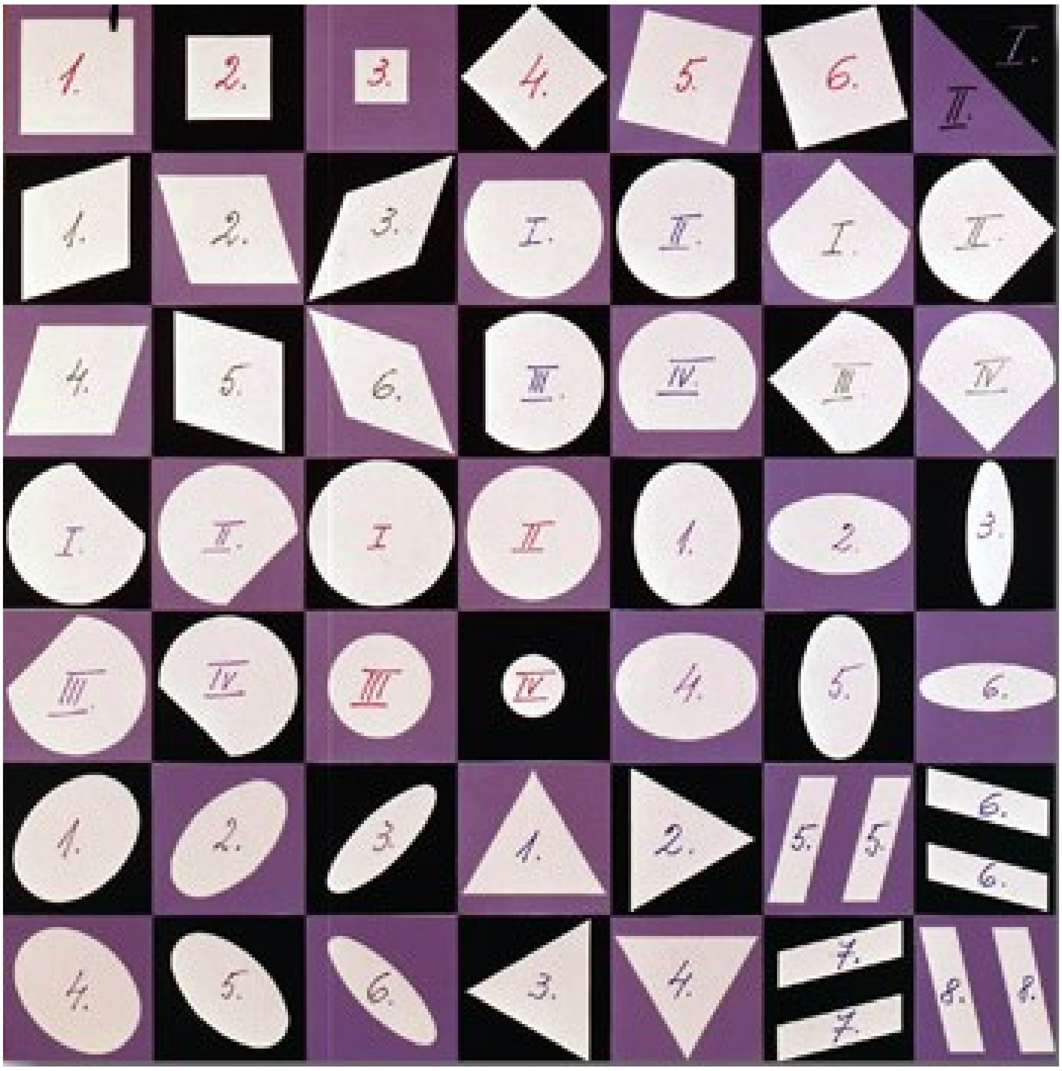


Figure 14 *Alphabet plastique: "The future is being laid out with the new geometrical city, polychromatic and solar, where plastic art will be essentially kinetic, multidimensional and communal, totally abstract and closely related to the sciences.".*

(Alphabet plastic; Vasarely 2004.)

As stated above, the basic Bauhausian shapes treated and manipulated in different ways, are the very basis of Op. Completely abstract shapes are the best in order to serve the perceptual purpose. The shapes are familiar to everyone, but they are not symbols in the general meaning of the word. A circle is not taken to represent eternity and nor does triangle inherently represent trinity. A circle exists as a circle and a triangle as a triangle. The meaning of their existence is only in relation to other shapes and to our perception. (Parola 1969, 31.)

As with optical illusions in general, Optical art also naturally emphasizes perception most of all (Parola 1969, 9): “Basically it distills the principles of art, using them singly and with force and commitment. It is the art of essentials, relying on total abstraction.” Parola also describes Op as a sudden and immediate art form; it is easy to understand because it is not dependent on the critic, the connoisseur, the artist, or the scientist. It is only what you see.

Other known Op artists besides Vasarely, are the ‘mother’ of Op; Bridget Riley; Jesús Soto; Yaacov Agam; Carlos Cruz-Diez; Julio Le Parc; and François Morellet. All these artists are the original ‘Op Art pioneers’, who were featured in the cutting-edge exhibition *Responsive Eye* (Popper 2009).

The movement lost popularity already by 1968. Although Op art is considered as an ephemeral art trend, it has had some permanent effects on the perceptual qualities of the spectator, on the relationship between artists, architects, and town planners, and on the systematic application of optical phenomena in technologically highly-developed art forms. (The Art Story Foundation 2014, Op Art; Popper)

“Everything we see can be seen in another way. Therefore, I ask myself; isn't everything an illusion anyway? Reality is but a question of perception, and perception inevitably varies according to one’s viewpoint. Different viewpoints lead to different dimensions.”
- Sandro Del-Prete

Sadro Del-Prete (1937 -) and Maurits Cornelis Escher (1898 - 1972) are examples of masters of a different kind of art that is more figurative, but also in which optical illusions play a major role. Their work finds its inspiration from impossible constructions and perceptions. (Del-Prete, Escher.)

Escher is a world-famous artist born in the Netherlands. In his work he plays with architecture, perspective and impossible spaces. To this day, his art and illustrations continue to amaze and inspire people all over the world. In the beginning of his career he made his own studies of plants, landscapes, architecture, buildings and insects. He used these studies later in his art, which features mathematical objects and operations like impossible objects (see p.10.), using things like the laws of symmetry, perspective and pattern (see p.55). (Escher; fig. 15.)

Del-Prete is a Swiss artist who has experimented with perspective in his work in an innovative and interesting way. By observing a chameleon and the movement of its eyes, he discovered a new dimension without the restrictions of the normal terms like front, back, top, bottom, right and left, but they were all the same. He observed that he could draw all the individual parts correctly in a picture, but only the whole piece appeared impossible. (Del-Prete.)

The most active association of Op nowadays seems to be a web association *Op-Art.co.uk.* They collect and share information about Op, its history and artists, as well as upcoming exhibitions and events. Their mission is “to keep Op Art alive and well by scouring the web and press for any Op Art related news and posting that to the site”. They are also looking for new talents using Op to feature on the site. Op art and artists are not totally extinct; they still exist. Today optical art is often made using computers and the influences of different art forms are so mixed, so it is difficult to define a pure Op. Even so, Op-Art.co.uk lists some of today’s interesting names like: Japan-based, *Yohei Yama*, *Charline Lancel* from Belgium, and the British artist *David Buckden*. (Payne 2012.)

As in Bauhaus, and minimalism more generally, the subjects of Op are simple and timeless – that’s why I think it will always remain valid and interesting.

Figure 15 *Waterfall by M.C. Escher (1961)*

3. FROM TWO DIMENTIONAL TO THREE DIMENTIONAL

An artist starts a traditional painting with a two-dimensional surface. With paint or some other medium they make the viewer to enter into their vision. Our world isn't two-dimensional and a three-dimensional world can't be created on a surface. (Payne 2012.) To represent the three-dimensional world on the two-dimensional surface, the artist has to use systems of illusion that create the impression of *space*, *depth* and *movement* out of the two-dimensional building blocks presented in chapter 3.2.1. p. 52. The challenge of the design is that a piece of furniture is usually a 3D object in a 3D world. This fact leaves out some of the illusions. An obvious but meaningful thing that I noticed was that the pieces of furniture usually consist of 2D surfaces. When internalizing this matter, the design work suddenly seemed to make sense.

I have laid out the objectives for the design work (see 1.3.3, p. 20 and 3.2.2, p. 62). The final design must also be simple enough to immediately see the "trick". Objects are meant for use and in our daily lives we do not have the luxury of time to observe them as we have in an art museum. Many times, the illusions of depth, size and shape also depend on the particular viewing position of the viewer (Shepard 1990, 131). If the illusion is only visible from a certain angle or point, do we then still talk about a piece of furniture or is it then a piece of art?

3.1 What Has Been Done?

Some applications of optical illusions were presented earlier in the chapter 2.2. on page 26. Optical illusions have also been a source of inspiration and the purpose of existence for some products and pieces of furniture. I don't want to reinvent the wheel, so to speak, so it is important to also know what has already been done in the same field. Here I have collected some examples that I personally find interesting and well-executed. The illusions behind them are analyzed and explained more thoroughly in the chapter 3.2.2. on page 62.

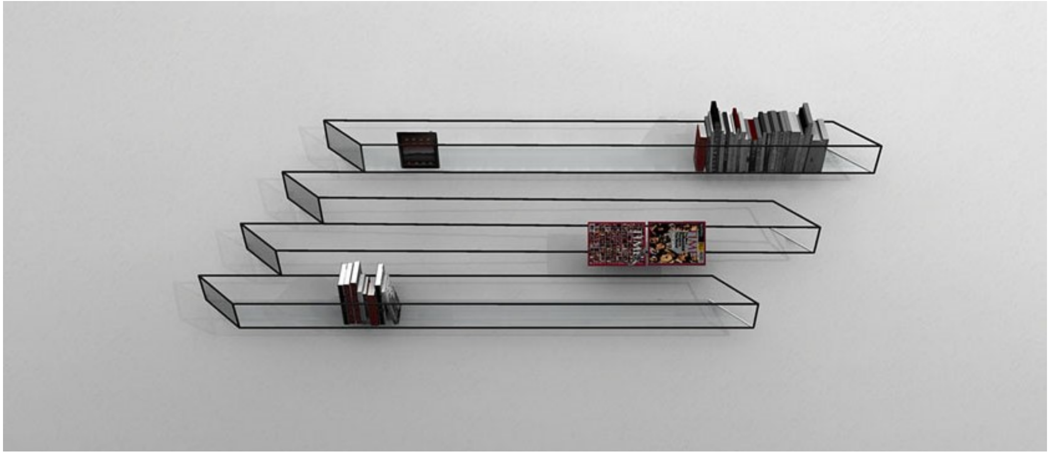


Figure 16

Figure 17

Figure 16. The “Bias of Thoughts” Bookshelf designed by ClarkeHopkinsClarke Architects is, in my opinion, one of the best executed products that uses optical illusion.

Figure 17. I was mesmerized when I first saw Bjørn Jørund Blikstad’s shelving system, Imeüble, in Stockholm Furniture fair 2012.

Figure 18. (p. 48) The next year, in 2013, I was happy to see Nendo as a guest of honor at Stockholm Furniture fair. Nendo’s chair from the “Thin black lines” collection has been one of the biggest influences on this thesis.

Figure 18

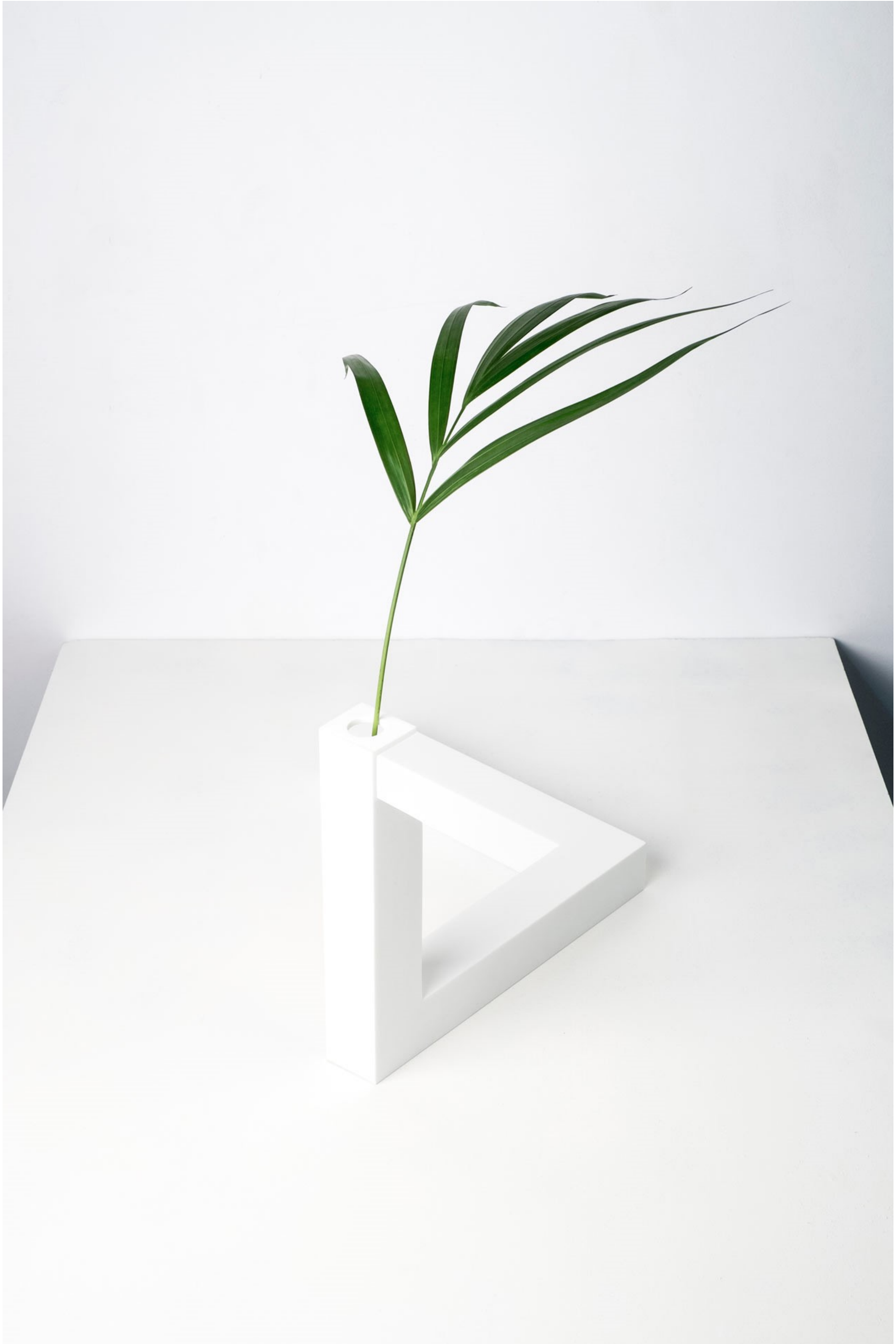


Figure 19

Figure 20

Figure 19. (p. 49) 90° vase by cuatro cuatros design studio is inspired by Penrose triangle (see fig. 40, p. 73).

Figure 20. Black hole rug by Daniel Malik.

Figure 21. (p. 51) Dmitry Kozinenko is a designer whose work I admire a lot. His aesthetics and design philosophy are very similar to mine. He designs unexpected and surprising objects that often play with the idea of perception. Field, a minimal shelving unit, is one of his most known works and is produced by Leibal.


100 years of Fashion Illustration
tangled alphabets
MoMA
ON LINE
MoMA
Picasso Guitars 1912–1914
Alvar Aalto
EDWARD HOPPER
TASCHEN
INTERIORS
NOW!
TASCHEN

Figure 21

3.2 What am I doing?

Successful examples of implementing optical illusions into a products already exist. How can I do the same? And how can I do it even better? What are the building blocks I need to know to be able to create something that contains an optical illusion but is also a usable product and doesn't feel forced?

When I had an understanding about how optical illusions work and what creates them, it was time to experiment with them using the methods of experimental prototyping explained in chapter 1.3.2, p. 12. The objective of the work was to find at least one concept to develop further into a product.

During the work I had to ask myself many times: "What am I doing?" Why should there even be optical illusion in a piece of furniture? When going back to my theoretical basis, I remembered again the meaning of the work. I hope you still remember it. If not, go back to chapter 2.2. on page 26.

3.2.1 THE BUILGING BLOCKS…

One of the strongest influences of Optical art was Bauhaus, a school of Architecture and Applied Arts founded in Germany in 1919 with a strictly disciplined style based on the fundamental geometric shapes of the cube, the circle and the rectangle. The school was shut down by Nazis in 1933 in Germany, but Bauhaus lived on with other schools starting in the US and Budapest. Also Victor Vasarely (see 2.3, p. 40) practiced in *Mühely*, the center of Bauhaus in Budapest. (Payne 2012; Vasarely 2004.)

Victor Vasarely's matrix, *Alphabet plastique* (fig. 14, p. 41.), is an example that the very same fundamental geometric shapes of Bauhaus apply in optical art, hence it is obvious that they play a role in the phenomenon of optical illusions more generally. Because of this, I analyze the elements of optical illusions through Optical Art and use a lot of examples from Op, describing the building blocks in the following examples.

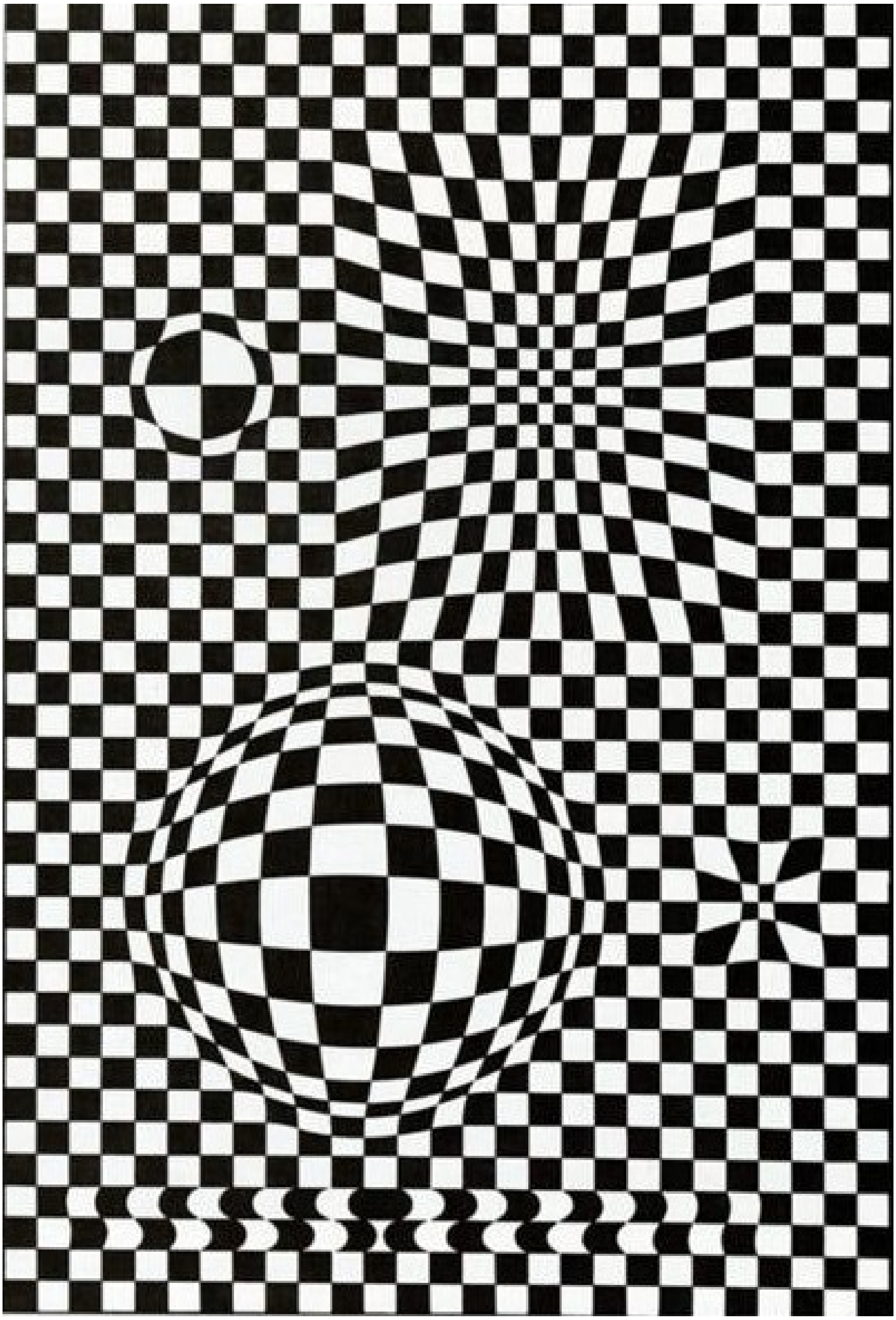


Figure 22 *Vega, Victor Vasarely (1957)*

Line is a basic element of every artistic work. (Parola 1969, 19.) Every geometric shape consists of a group of lines (O'Keeffe 2012). Traditionally, when describing a line in artistic sense, we might use words like expressive, dynamic, strong, sensitive or nervous. Op artists adored a type of line that was considered unaesthetic before - a simple, hard-edged and unadorned line. (Parola 1969, 31.)

From late 60's onward, Victor Vasarely started playing with the deformation of the line. He defined his "universal structures" and created the series that is probably his most popular and widely known (fig. 22, p. 53.), presenting pieces where the elements give illusions of the forms escaping from the flat surface (Vasarely 2004). I find these works where he attempts "to evoke the unattainable universe of galaxies and the gigantic cosmic pulsation" (Vasarely 2004) extremely fascinating and inspirational.

The complete abstractness and familiarity (universality) of the basic geometric shapes serve the perceptual purpose best in optical illusions (see 2.3. p. 40), but how can we use them? A line won't necessarily make an optical illusion on its own. What tools and devices are the base of optical illusions that make them work?

As stated before, the very basis of optical illusions is perception (see 2.1. p. 22.). The fundamental aspect of creating an optical illusion is actually understanding of the laws of perception:

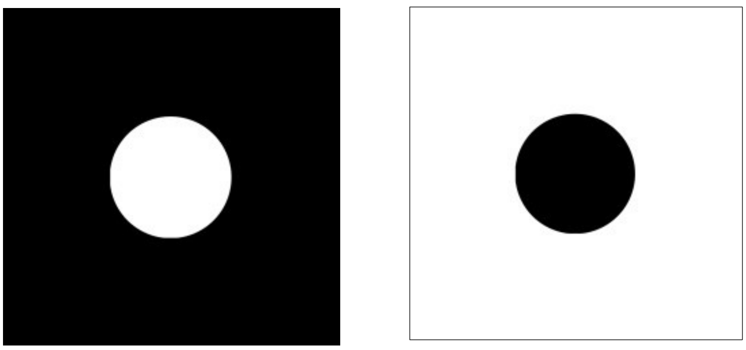


Figure 23 *We tend to understand the darker parts as the figure and lighter parts as ground. Lightness and darkness of the areas doesn't have any effect to the relation of negative and positive space (Negative and positive, p. 68).*

1) FIGURE-GROUND

We have a natural tendency and capacity to separate an object from its environment (see fig. 23, p. 54). Different factors such as size, shape, distance or value can determine which part of visual information is received as figure and which is the ground. The visual illusion is achieved when the eye can not choose between the two and is forced to repeatedly shift from one to the other. (Thurston & Carraher 1996, 19.)

2) ASSIMILATION AND CONTRAST

If all our senses responded to all external stimuli around us, we would lose our mental health in few minutes. Our filtering system to minimize the stimuli and to create focus and unity is called assimilation. (Parola 1969, 13.)

Contrast is the antonym of assimilation. It accentuates differences. Together contrast and assimilation are the foundation of our perception - and of optical illusion, the first impression and an ultra-rapid summary of reactions. (Parola 1969, 14, 15.)

3) GROUPING

The world around us is not as simple as the examples above. There are some principles to help to explain how we interpret complex structures and multiple stimuli. The most well-known of those, which *Rene Parola* (1969, 22 - 30) also uses as an example, is *Gestalt laws of grouping*:

Proximity: “Objects that are near one another have a tendency to group”

(fig. 24, p. 57.)

Similarity: “All similar things, comprehending areas with similar color, size, texture and value, have a tendency to group” (fig. 25, p. 57.)

Good figure: “perceptual ability to predict a total entity from a minimum amount of information or stimuli”. There are three indicators that help in determining the “goodness”:

- **Closure**: “The grouping of elements that makes for a more complete or closed form” (Figure 26.)
  Closure means our natural tendency to fill in gaps or spaces in a visual pattern. Closure is experienced when a group of disjointed and separate shapes is suddenly understood as a part of a larger visual recognizable subject. (Thurston & Carraher 1996, 19.)

- **Symmetry** as a law of grouping means: “We tend to perceive an image that appears symmetrical as an entity, and we try to blend an asymmetrical shape into a balanced one.” (Figure 27.). Symmetry also has a bigger role in Op when it comes to the composition of the image: in Op, symmetry relies on equality of shape. The contours of the figures are exact; there is no distraction or asymmetry. Even the paint must be uniformly applied and brushstrokes are avoided. (Parola 1969, 31, 32.)

- **Common fate & Progression**: “Objects that have the same trend of motion have a tendency to group” (Figure 28.)

  Progression is an effective tool to create optical illusions. It is not purely creating symmetries or patterns (see: Pattern, p. 58), but more like “moving” from one stage to another. The simplest example is repeating a shape within itself in a way that the size of the image changes, but the width of the line is constant relation to the negative space. This is called consecutive progression (fig. 29). (Parola 1969, 61.)

  Sequential progression allows movement in all directions. It is possible to increase, decrease, turn or reverse, but there is always a relationship to the previous stage. The construction can be based on intuition, but it can also be constructed logically based on fundamental mathematics (Parola 1969, 70.)

- The Gestalt psychologists also name one more law of grouping called the ***Law of Past Experience***. This means that visual stimuli can be categorized according to past experience (see 2.2, p. 26). (Parola 1969, 29.)

Figure 24 *Proximity*

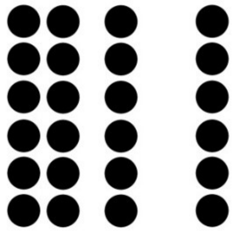


Figure 25 *Similarity*

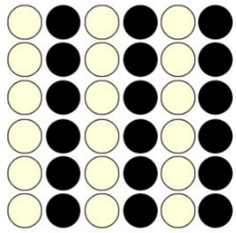


Figure 26 *Closure*

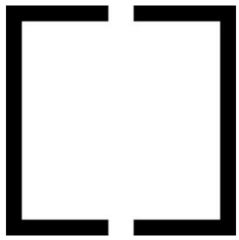


Figure 27 *Symmetry*

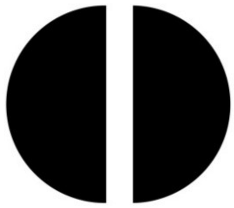


Figure 28 *Common fate*

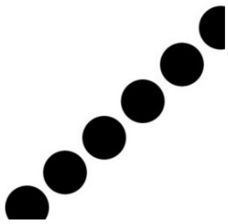
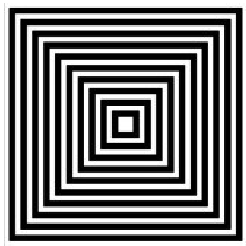


Figure 29 *Progression*



4) COLOR

We detect light and dark much more easily than color. That's why black and white have replaced color in many instances in optical illusions and in Op. Black and white are the ultimate in contrast and express powerful optical illusions. However, with the right color combinations, it is also possible to create illusions without black or white. Yellow and violet have an innate contrast whereas green and blue are almost devoid of contrast because of their similar intensity. It is also possible to create tension between colors using warm cool relationships (Parola 1969, 117, 128.)

5) PERSPECTIVE

Some techniques used in Optical art are as old as the history of linear perspective in Western art, starting from the early 15th Century by the Florentine architect and painter *Fillipo Brunelleshi* (1377-1446). (Payne 2012.)

Traditional perspective techniques were originally developed for the flawless representation of the natural world in art. Despite the non-representationality of Op, the Op artists used these techniques extensively. (Payne 2012.)

Linear perspective is not the only one. Dark-to-light progression can be used as a part of structural pattern mimicking the way light hits the foreground in reality retains its "own" color, while parts with less contrast merge into the background and seem more distant (see Black hole rug by Daniel Malik (fig. 20, p.50.) & Trompe L'oeil, p. 75). (Parola 1969, 97)

6) PATTERN

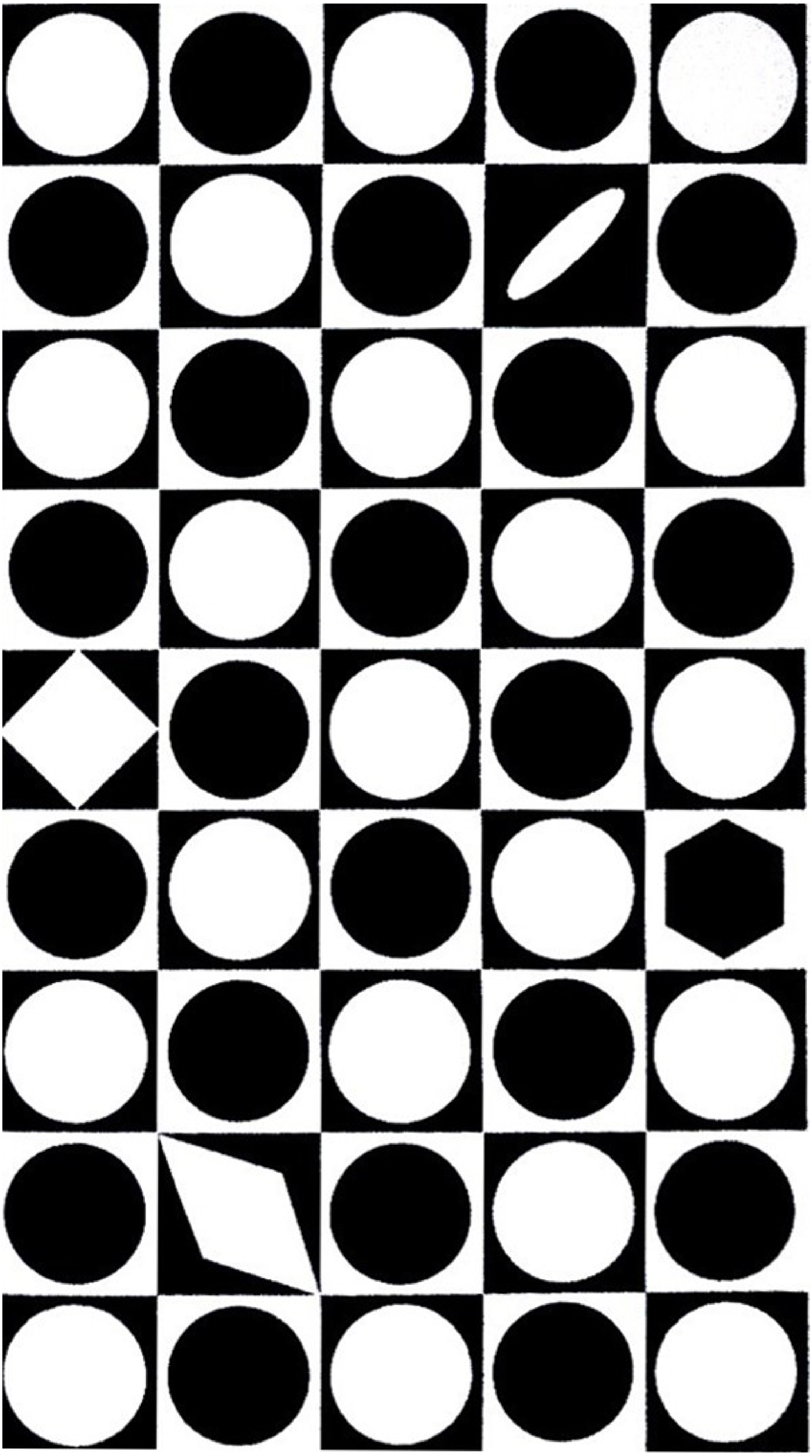
It is good to remember that the laws of perception, presented above, don't concern only our visual sense, but also affect our other senses (Parola 1969, 22). These laws are easy to list and understand separately but, as mentioned before, the world is not that simple. We use these principles of grouping subconsciously, which makes it difficult to identify them when analyzing optical illusions with multiple techniques (see fig. 30, p. 59). But to understanding these laws separately is essential if we are to use them as a tool for analyzing and creating new illusions.

Patterns can be identified using a combination of the many different methods listed above. Still, our perception seeks simplicity, and the concept of a pattern is built in our perceptual reactions. We use assimilation subconsciously, which iswhy we don’t see a chessboard or black and white kitchen tiling as separate units, but rather an entity. Pattern is one of the main terms used when talking about optical illusion. (Parola 1969, 78.)

According to Parola (1969, 33.), a pattern is usually homogenous. It is: “multiplying the objects of perception and causing complex visual relationships”. It is “…nothing more than the exact, orderly, symmetrical repetition of an image, and nothing less than total unity” (Parola 1969, 78). For example, the illusion of movement and cohesion (See fig. 6, p. 25) are easy to create by using proximity and closure of patterns (Parola 1969, 94)

Figure 30, page 60

When increasing the visual stimuli, analyzing becomes trickier. We first might see contrast: there are dark and light areas. Second would be figure and ground: the checkerboard is larger and seems to surround the objects, so it is negative. Third comes similarity: most of the objects group by the circular shape and the two remaining object groups because of the dissimilarity.



“Problem grows from a purpose. There needs to be a purpose to have a problem.”
(Michalewicz, Fogel 2000, 2)

3.2.2 … TO EXPERIMENT ILLUSIONS…

Optical illusions have been grouped in many different ways by different people (1.2. p. 8). For example, Michael Bach (2017), Professor and Doctor of Functional Vision Research and Electrophysiology, has sorted out 132 different *Visual Phenomena* and *Optical Illusions* in eight different categories: Motion & Time, Luminance & Contrast, Color, Geometric- & Angle Illusions, Space, 3D & Size Constancy, Cognitive- / Gestalt Effects, Specialties with faces (and Auditory Illusions).

I compared the different categorizations trying to find one that would suit my purposes. As none of them suited perfectly, I sorted out six different optical illusions for the experimental investigation. They all present different characteristics and possible potential based on my existing knowledge, intuition and interests (see 1.3.2. Intuition, p. 17).

As mentioned earlier, to be able to have a successful explorative prototyping process, the examiner needs to know why and how they are doing the work (1.3.2. Explorative prototyping, p. 12). The key goal in all of the experiments is the same: *To find a structure with an optical illusion that can be used as a part of a product*. The secondary goals are its newness, interestingness, necessity, potential for manufacturing or production (materials, parts, fasteners, material & tooling costs). In all cases, I determined a different technology or a method I wanted to examine. Setting a short timeframe was not successful in all of the experiments. For all of the experiments, I set a timeframe of one hour in the beginning. This is enough time to get an idea if an idea could work or not. If the outcome was interesting, I allowed myself to continue; some of them were totally engrossing, where I couldn't stop and spent far too many hours working on them and continued until I almost created a ready product. Steel is used as the material in most of the cases because it is a familiar material for me, therefore prototyping and working with it is fast and effortless.

When analyzing the results, one needs to keep in mind the original purpose of a prototype, which, according to Ulrich & Eppinger (2012, 294) are: learning, communication, integration and milestones. All of the prototypes don't need to be appropriate for all the purposes (Ulrich & Eppinger (2012, 297). Some of the prototypes of this project are experimental, early stage prototypes and my main objective for creating them was to learn something from them. It is also easier to communicate ideas to other people through something physical.

ILLUSION						
	CRITERIA	GRADE (1-5)				
1.	Does it create optical illusion?					
2.	Does/could it work as a (part) of a structure?					
3.	Newness / interestingness					
4.	Potential for manufacturing/ production methods?					
5.	Experimental prototyping process					

Figure 31 *Concept screening matrix*

There are various ways to do the analysis and concept selection. The validation may be purely based on test data and the results. The concept selection can be made from different points of view: sometimes the main factor may be the user needs, while in other cases it may be the manufacturing methods or production costs. (Ulrich; Eppinger, 2000, 137.)

To evaluate and compare the prototypes, I created the *Concept screening matrix* (Figure 31) for an easier visualization about whether the prototype achieved the desired objectives or not. In the matrix, the main goal is the top-most criteria and when proceeding through the additional goals down the rows, the importance in the validation increases. Also, the amount of total points (colored boxes) is a factor for the determining the success of the validation. I also grade the success of the experimental prototyping process. The matrix is a supporting tool for decision making to choose the most promising experiment for further development. A large part of the validation process is based on intuition and inspiration (1.3.2. p. 17). All of the matrices comparing all the six chosen illusions are on the pages 80 – 81. The following chapters explain my experimental prototyping process illusion by illusion:

REVERSIBLE IMAGE

Bjørn Jørund Blikstad's shelving system, Imeüble (see 3.1. p. 47), is an example of a reversible image. This phenomenon means that, with visual concentration, we are able to reverse a certain kind of an image and see two different shapes. An outline figure of any geometric figure drawn in three dimensions can be reversible. (Parola 1969, 35, 41; fig. 32.)

Reversion can also happen between positives and negatives in an image. This means a picture with light and dark areas equally important. By concentrating on the image (fig. 23, p. 54), we can choose the dominant figure. (Parola 1969, 44.)

Reversible images are ambiguous figures (see 1.2, p. 10). One of the simplest and the most common ambiguous figures (reversible image) is the Necker cube (fig. 33, page 66), named after its creator, Louis Albert Necker (1786-1861). One reason why the Necker cube is such an interesting example is that it cannot only be seen in two different ways, but it is three-way ambiguous. The cube can be seen in 3D in two different ways: with the front face of the cube below and with the front face of the cube above. It is also possible to see the image as a 2D series of lines (Donaldson & Macpherson 2017.)

I experimented with Necker cube and its variations on a 3D modeling program with quick line drawings (fig. 34, p. 66). It is a fascinating and simple shape but doesn't inspire me enough. Where could it be used? As a part of a storage system? As a table leg structure? In the end, the Necker cube in a 3D reality is just a cube (fig. 45, p. 80).

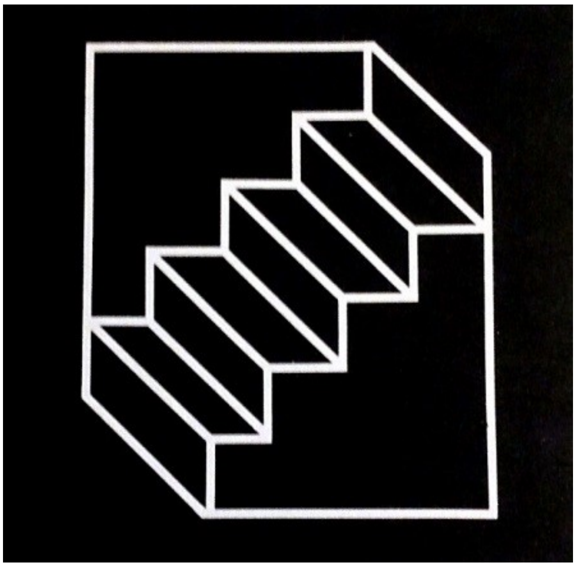


Figure 32

Schröder's staircase is a classic example of reversible image.
After visual concentration the stairs can be reversed.

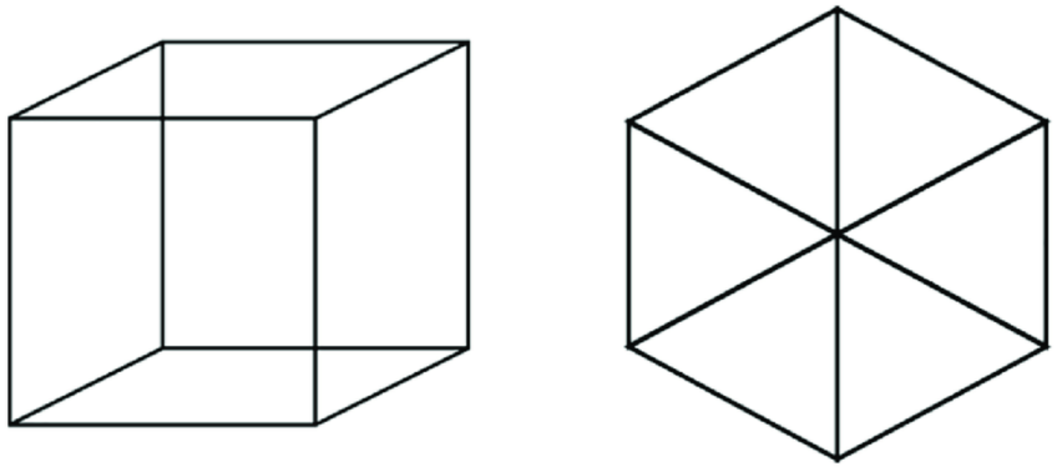


Figure 33 *Two different versions of the Necker cube*

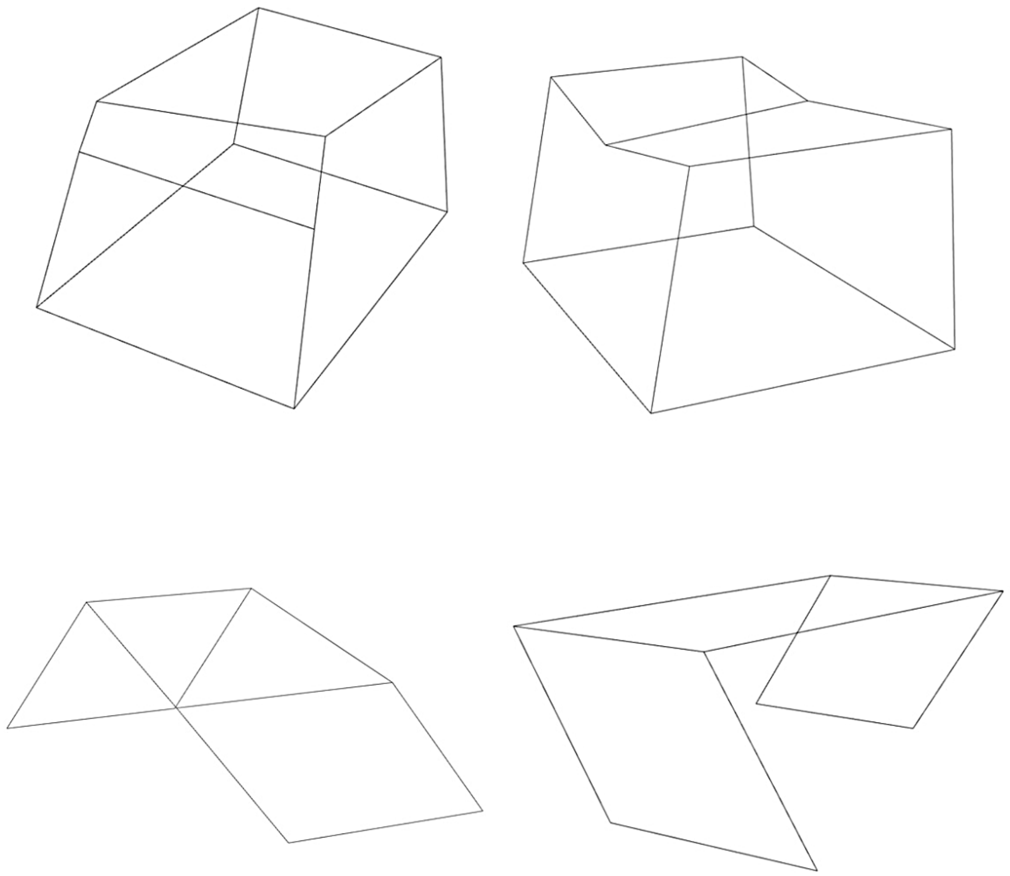


Figure 34

Line drawings of 3D objects that could be seen different ways as 3D objects or 2D shapes, depending on the point of observation.

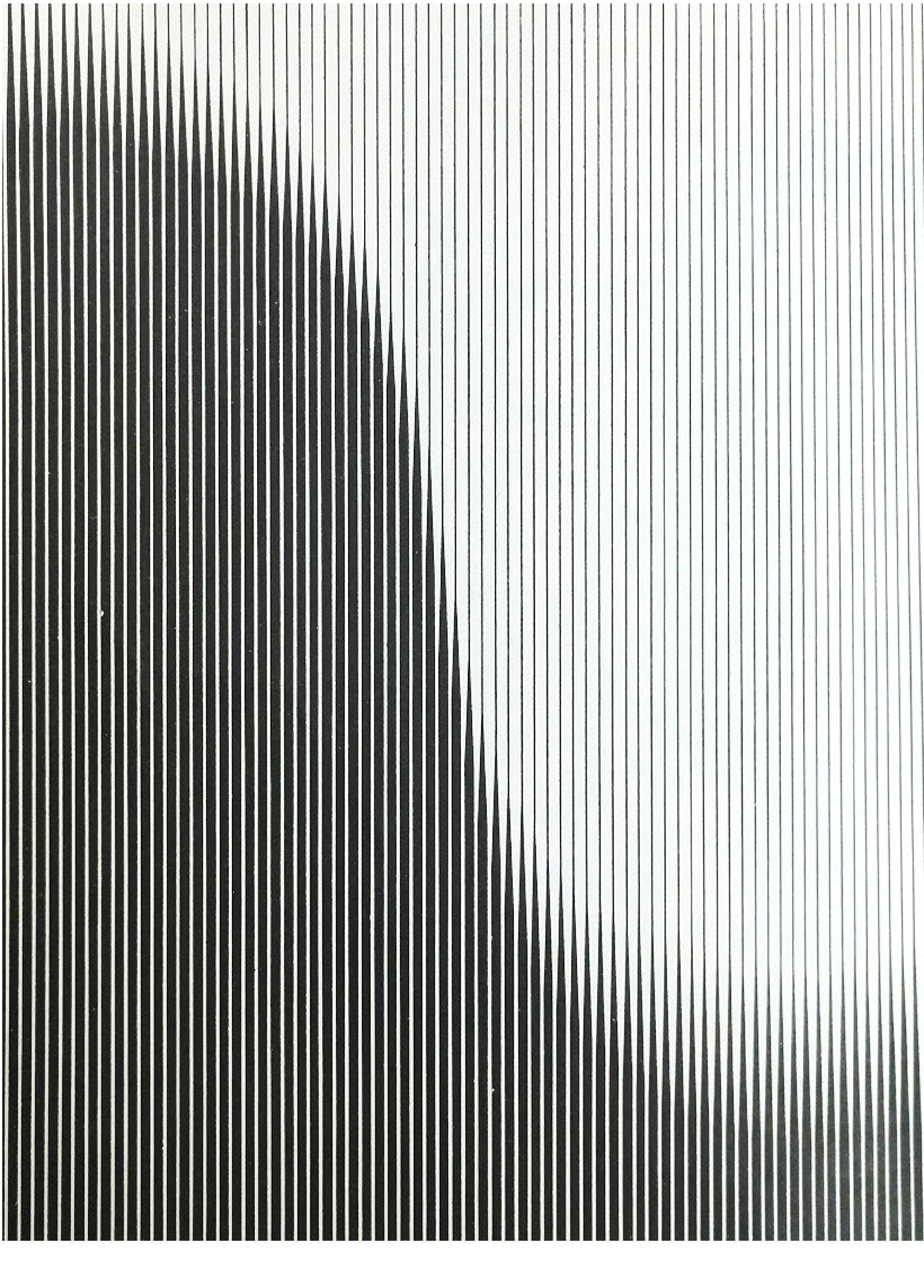


Figure 35 *Detail of a newspaper advertisement. Design: Herbert Kapitzki*

NEGATIVE AND POSITIVE

Figure 35, p. 67 was my inspiration for the experiment where I explored how to implement the theories of negative and positive space in 3D.

If we can see one part standing out from the rest, this area is usually called the figure. The area we regard as less important is referred to as the ground (see Figure-Ground, p. 55). The figure can also be called a positive space and the ground as a negative space. In general, negative space surrounds positive space and seems like it extends continuously behind the figure. Usually, negative space is larger in size but is still considered less important. Positive space is usually centrally located and defined more clearly. If negative and positive spaces are equal in size, then the simpler and more regular one becomes positive. (Parola 1969, 18; fig. 23; fig. 46, p. 80.)

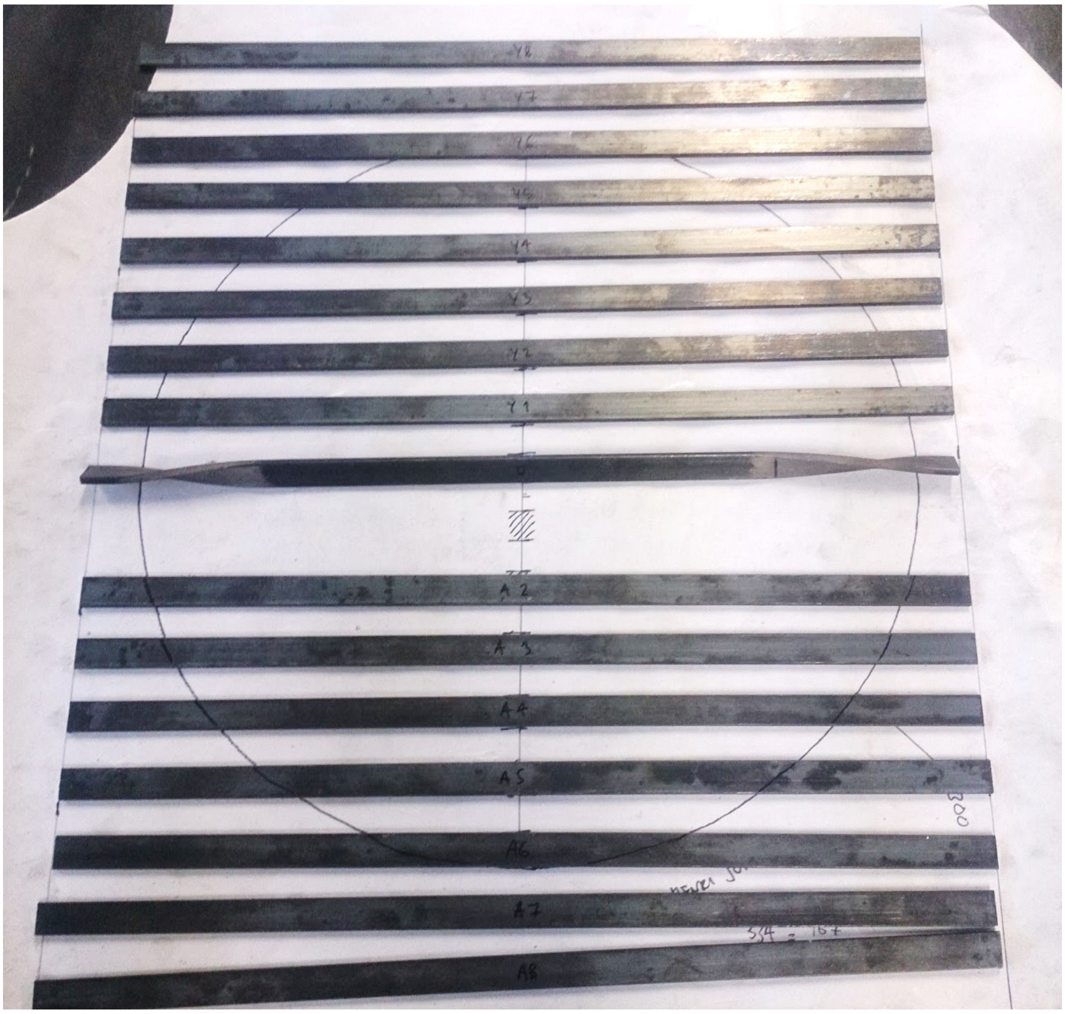


Figure 36 *Twisting flat steel bar*

I came up with an idea that, by twisting a flat steel bar, it is possible to create similar effect as in the image, in 3D. Adding multiple steel bars next to each other and changing the place of the curl, it was possible to create shapes (fig. 36).

This technique was totally engrossing to me and the resulted in the Sun & Moon tables (fig. 37, p. 70), which were exhibited together with the chairs presented later (p. 71; Appendix 3). The tables gained a lot of interest but producing them is difficult. Twisting steel is a traditional blacksmith working method. I know it is possible to produce twisted steel in an industrial environment (see Appendix 2: Tärnö chair by IKEA), but the production costs would be very high for a small side table. Therefore, this is not the best outcome of my experiments thus far in terms of price and ability to be produced.

Figure 37

The theories of figure and ground are exploited in the Sun & Moon side tables.

MOIRÉ PATTERN

Moiré patterns are all around us: they might appear in the overlapping of fences, baskets or nylon curtains. The name originally comes from a name of a type of textile, with a rippled or 'watered' appearance, traditionally made of silk but now also of cotton or synthetic fiber. Moiré patterns can be created with any pattern of geometric shapes. Only negative or positive space is needed in order for the pattern to function. The most effective Moiré patterns are usually achieved using line patterns and is produced when two sets of lines, with any shape or direction, are superimposed at an angle of less than thirty degrees, thus the intersecting lines become magnified and appear to fill in the space. (Parola 1969, 55; Figure 38.)

At first, I played with the idea of two overlapping perforated metal sheets (fig. 39, p. 73) and sketched a set of overlapping tables. It is hypnotizing to watch the shapes move, become bigger and smaller again and again. One advantage of using Moiré patterns is that the illusion isn't dependent on the viewing point but instead "follows" the viewer. The illusion also isn't "forced", but it is already embedded within the structure. A successful Moiré pattern only requires two overlapping surfaces for the illusion to be automatically visible.

Moiré patterns are captivating, but, as they can be seen in a lot of places, they don't create a wow effect or a feeling of newness. This got me thinking: what if the illusion is not in one product, but rather that the illusion happens when a lot of products with lines are placed in a space?

This idea caused me to get a bit sidetracked with the focus of this thesis. I had an exhibition at the same time where I produced a set of chairs with horizontal and vertical lines, thinking they could be part of the thesis (see: Appendix 3). In the end, they were useful to the explorative prototyping approach to the research here, but not in the way I had intended. While the Moiré effect can be seen when there are many chairs in a space, and though they are a very decent pair of chairs, this is not truly what I hoped to pursue and to be the outcome of my experiments (fig. 47, p. 80).

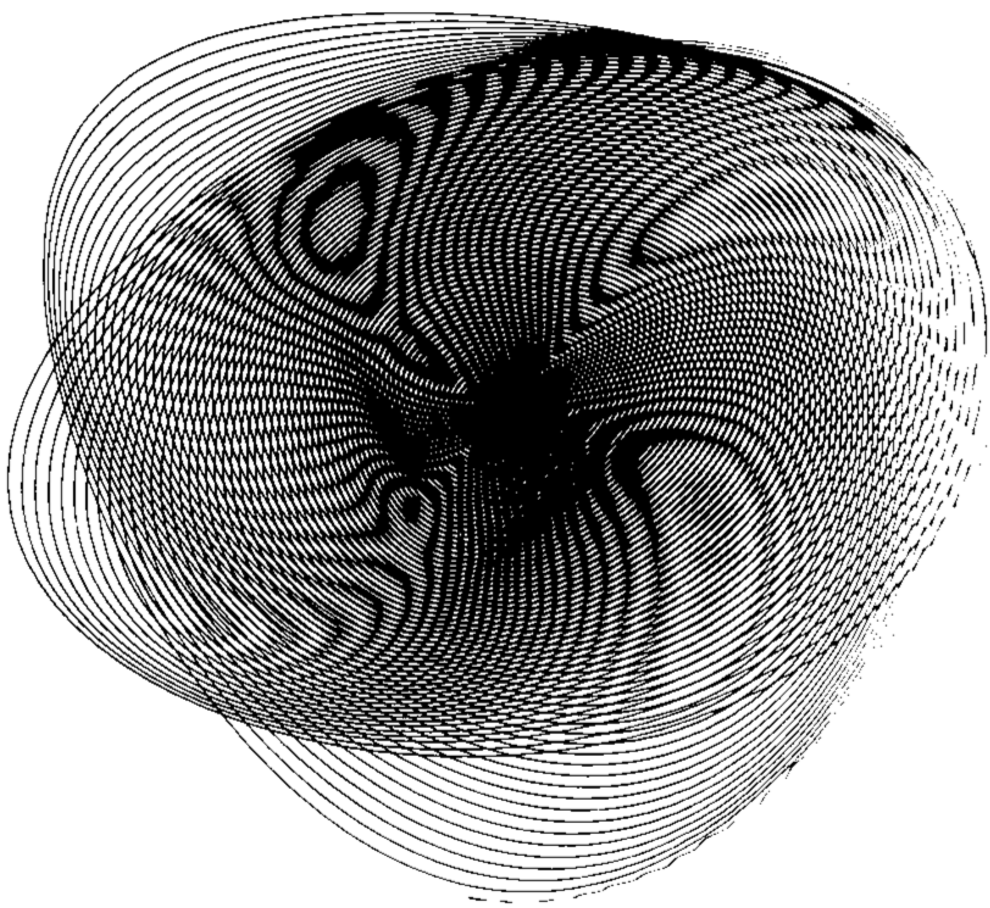


Figure 38 *Moiré pattern*

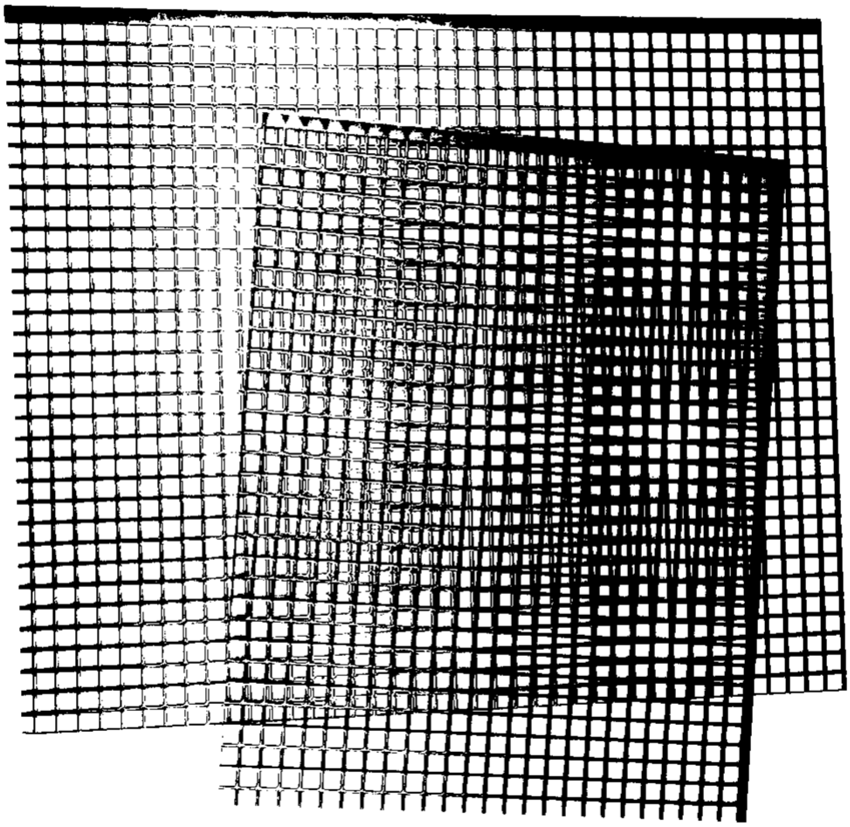


Figure 39 *Two overlapping perforated metal sheets create Moiré Illusion.*

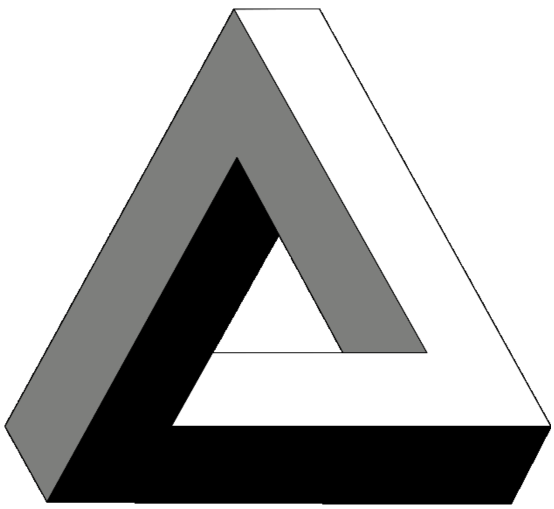


Figure 40 *Penrose triangle is the simplest impossible object*

IMPOSSIBLE OBJECTS

The possible interpretations of an impossible object are not simultaneously compatible but are a never-ending rivalry of seeing between the two (or more) possibilities. “The 90°” vase by *cuatro cuatros* design studio and the “Bias of Thoughts” Bookshelf designed by *ClarkeHopkinsClarke Architects* are elaborate examples of Impossible object in three dimensions (see 3.1. p. 47 – 49).

This would have been an interesting area to dive into deeper. If these objects are possible to recreate in 3D, are they actually impossible? I thought of creating a collection of (Im)possible objects. I worked on sketching and modeling for an hour, but there are actually a lot of good existing examples of impossible design objects, so it didn’t give much more attention to it. One hour is not enough to explore this illusion deeper. Also, one shortcoming of these objects that I do not personally like is that they are only impossible from a certain vantage point. (fig. 48, p. 81.)

TROMPE L’OEIL

The painted fake speed bumps (2.2. p. 30) and the Black hole rug by Daniel Malik (3.2. p. 50) are examples of Trompe l’oeil (French = to deceive the eye). This technique is used in fine arts to represent the perspective of the images as realistic as possible (Rock 1984, 90-91).

The deception, once again, is perfect only from a certain point of perception, which is the point which is the apex of all the vanishing points, or the center of the projection. When the spectator moves away from the designated point of observation, the image starts to look distorted. (Rock 1984, 91-92.)

Could I adapt or modify this technique to better fit my purpose? The idea of *deceiving the eye* by mixing reality and unreality matches perfectly with my objectives.

Shadows are a way to perceive perspective. We are used to light coming from above us, which creates shadows underneath objects. By reversing the direction of light, it is possible to trick, for example, our perception of convex and concave. (fig. 41, p. 76; Thurston 1996, 12.)

The concept of shadows stayed in my mind for a while. One sunny spring day when I was walking home, I noticed that my shadow was long due to the angle of the overhead light from the sun and got an idea to create fake shadows for objects. This experiment was initially more for fun than research. I couldn’t find a way to apply a fake shadow in a structure, but I think one of the ideas was worth executing. The concept of the Ombre mirrors (fig. 42, p. 77) is understandable, but I don’t think the concept is strong enough (fig. 49, p. 81) to be considered an Optical illusion.

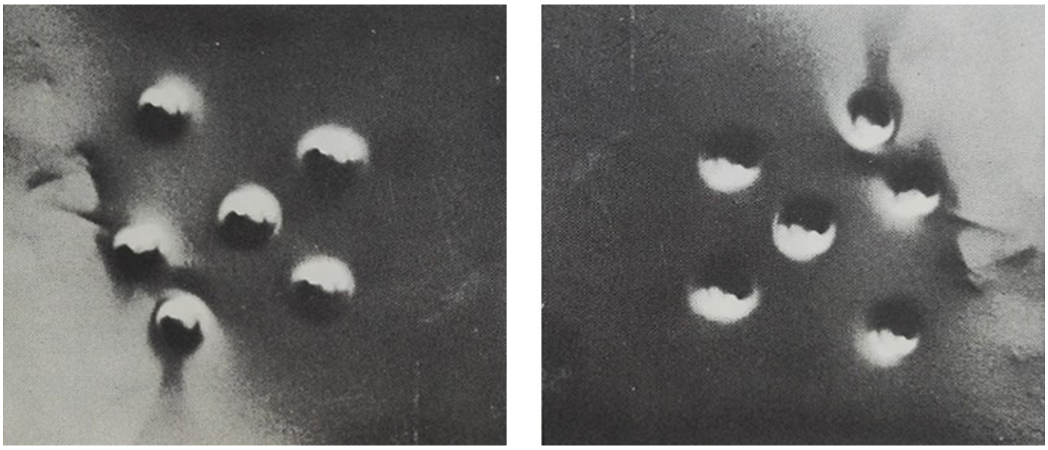


Figure 41

When a shadow pattern is inverted a convex form may appear concave.

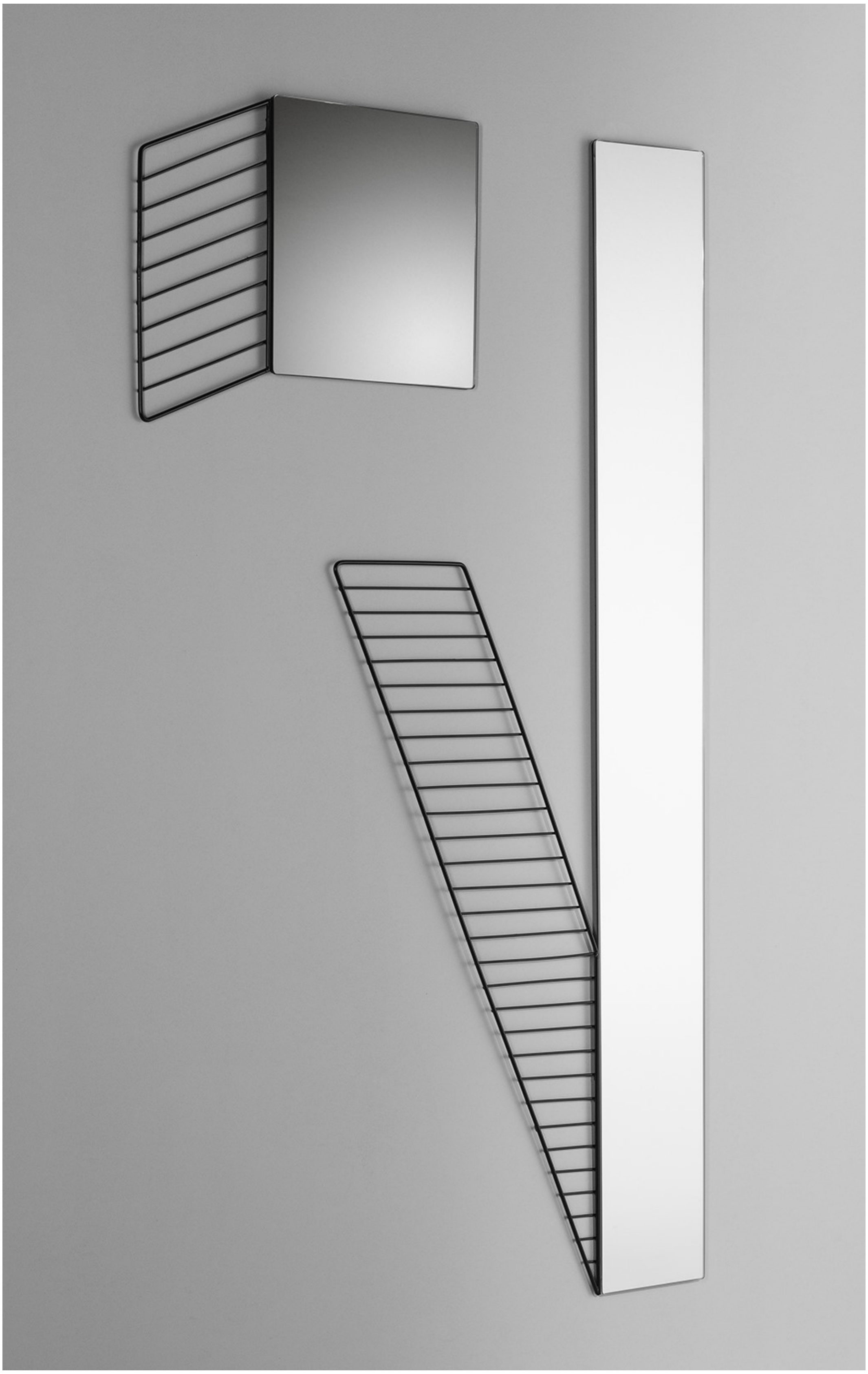


Figure 42 Ombre mirrors

INFLUENCE OF ANGLES

One more fundamental optical illusion phenomenon is the *influence of angles.* The most straightforward example of this illusion is the *horizontal-vertical illusion,* which simply means that a vertical line looks longer than a horizontal line of equal length (Gregory 1968, 48). Another and very common example of the influence of angles is the *Zöllner illusion* (fig. 43, p. 79), named after its inventor. It is an image with negative and positive parallel areas, but where the lines do not appear parallel because of the small intersecting angles. (Gregory 1968, 49; Parola 1969, 47, 55.)

After a quick sketching, modeling and benchmarking, I found this subject to be underexplored. I wanted to explore this phenomenon more at the workshop, where I made a small "step" out of a thin steel rod. And like in the *Negative and Positive* experiment, I created multiple similar rods, placing the next one on top of the step of the previous one (fig. 44, p. 79). I liked the illusion of a depth the steel rods created together. Could this structure work as a part of a product (fig. 50, p. 81)?

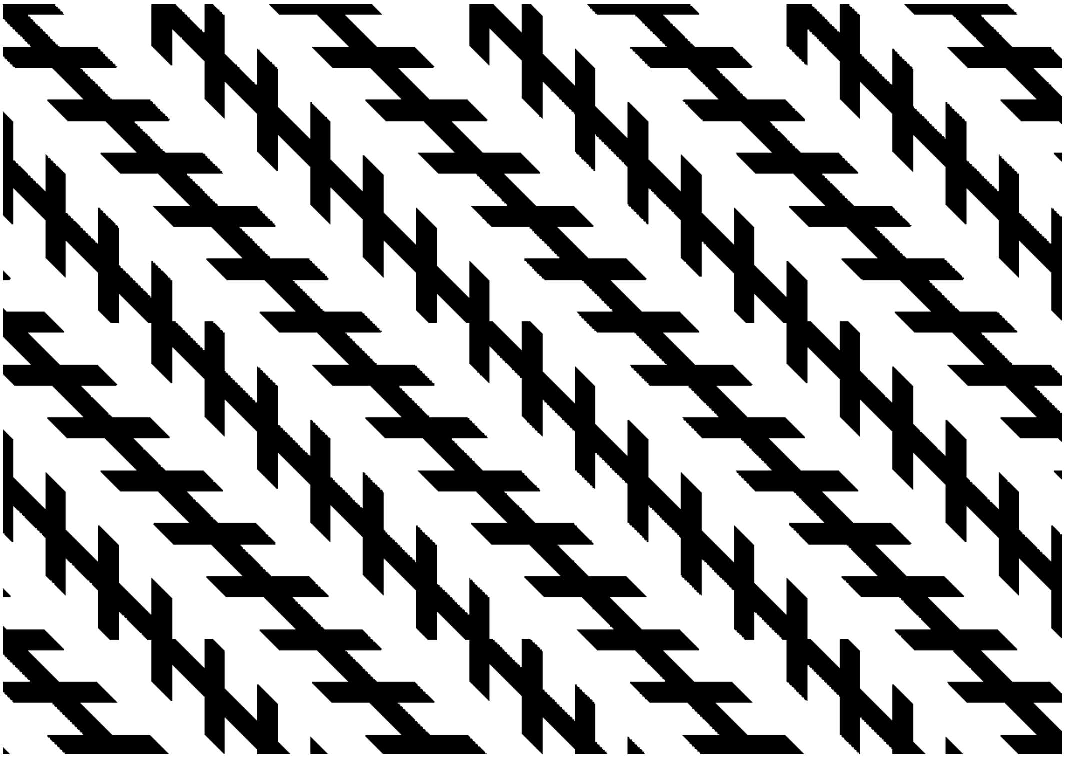


Figure 43 *Zöllner illusion*

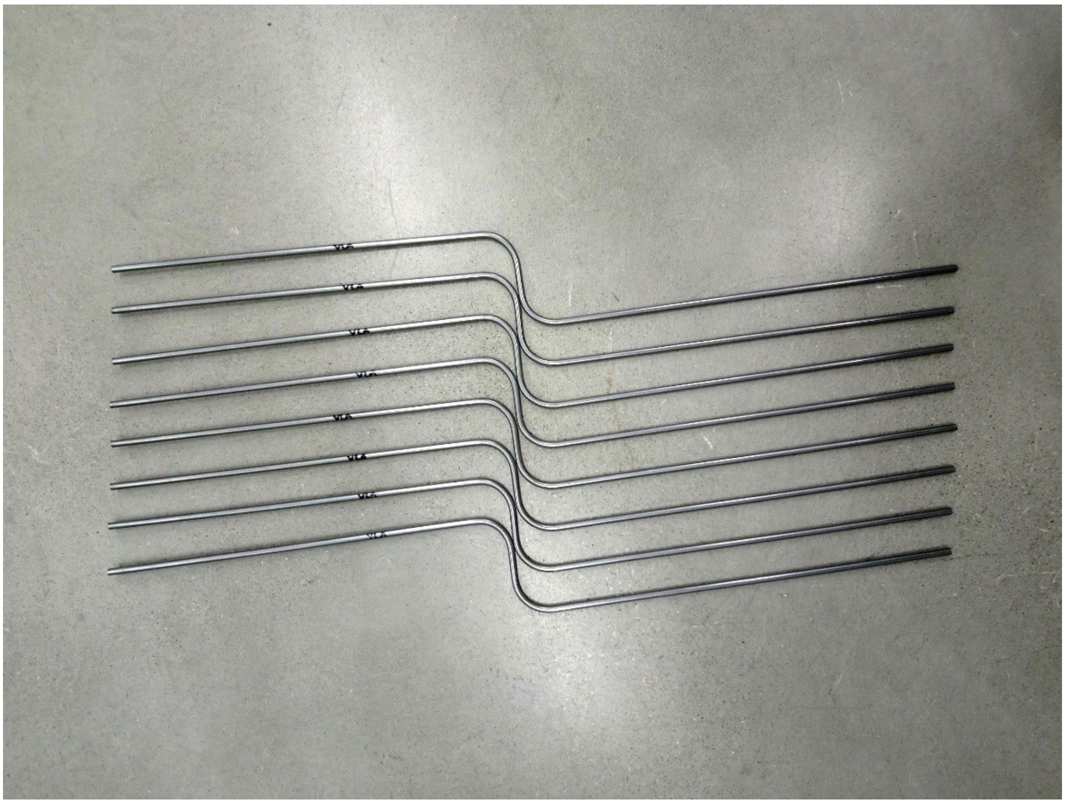


Figure 44 *The steel rods create an illusion of depth.*

ILLUSION: **Reversible images**						
	CRITERIA	GRADE (1-5)				
1.	Does it create optical illusion?	■	■	■	■	
2.	Does/could it work as a (part) of a structure?	■	■	■		
3.	Newness / interestingness	■				
4.	Potential for manufacturing/ production methods?	■	■	■		
5.	Experimental prototyping process	■	■			

Figure 45 *Concept screening matrix for Reversible images*

ILLUSION: **Negative and Positive**						
	CRITERIA	GRADE (1-5)				
1.	Does it create optical illusion?	■	■	■		
2.	Does/could it work as a (part) of a structure?	■	■	■	■	
3.	Newness / interestingness	■	■	■	■	■
4.	Potential for manufacturing/ production methods?	■				
5.	Experimental prototyping process	■	■	■	■	■

Figure 46 *Concept screening matrix for Negative and Positive*

ILLUSION: **Moiré pattern**						
	CRITERIA	GRADE (1-5)				
1.	Does it create optical illusion?	■	■			
2.	Does/could it work as a (part) of a structure?	■	■			
3.	Newness / interestingness	■				
4.	Potential for manufacturing/ production methods?	■	■	■		
5.	Experimental prototyping process	■				

Figure 47 *Concept screening matrix for Moiré pattern*

ILLUSION: **Impossible objects**						
	CRITERIA	GRADE (1-5)				
1.	Does it create optical illusion?					
2.	Does/could it work as a (part) of a structure?					
3.	Newness / interestingness					
4.	Potential for manufacturing/ production methods?					
5.	Experimental prototyping process					

Figure 48 *Concept screening matrix for Impossible objects*

ILLUSION: **Trompe l'oeil**						
	CRITERIA	GRADE (1-5)				
1.	Does it create optical illusion?					
2.	Does/could it work as a (part) of a structure?					
3.	Newness / interestingness					
4.	Potential for manufacturing/ production methods?					
5.	Experimental prototyping process					

Figure 49 *Concept screening matrix for Trompe l'oeil*

ILLUSION: **Influence of angles**						
	CRITERIA	GRADE (1-5)				
1.	Does it create optical illusion?					
2.	Does/could it work as a (part) of a structure?					
3.	Newness / interestingness					
4.	Potential for manufacturing/ production methods?					
5.	Experimental prototyping process					

Figure 50 *Concept screening matrix for Influence of angles*

3.2.3 …TO CREATE ILLUSION IN STRUCTURE

The most interesting result, and thereby the topic I chose for further exploration, was the Influence of angles. After the first sketch, it was clear that the effect needs enough space on both sides of the “curve” to be as effective as possible. This means the product should be either high or wide. Pretty early in the process I had the idea that the effect could be used as a structural part of a bar stool. (fig. 51, p. 83.)

I tested different possibilities on the 3D program Rhinoceros. I wondered whether the steel rods should be vertical or a bit tilted. For the foot rest to be able to sit perfectly at the right height in between of the side structures, and for the structure to not to grow too wide, a 10° rotation was needed. What is original in this piece is that from one side it is hard to tell the correct structure of the stool but from the other side it looks just like any bar stool. From this “normal” side, the rotation angle of the leg is 3°. I made the leg structure frame from a Ø10mm steel rod and the inner rods are made from a Ø6mm steel rod. The sitting height of the stool is 740mm. The seat is 30mm high, 330mm deep and 360mm wide. The seat part is upholstered by a talented upholsterer, Marja Laine. The total depth of the bar stool is 410mm and width 390mm. The structure is finished with a glossy black powder coating RAL9005. (fig. 53 & fig. 54, p. 85 – 86.)

In the end, the actual creation of the bar stool was very fast. I think this is because of the thorough research process I had done. I ended up making three of them. While making them, I reflected about how the process would be if the stools were produced more industrially. Certainly, it is not the most production friendly product, but I have seen more difficult products successfully produced using industrial methods. All of the Ø6mm steel rods are identical, which makes the process easier. Then all it requires is bending and welding of the rods. Also, if produced industrially, the inner rods would be welded to the sides of the Ø10mm frame. As I made them by hand, I chose an easier way to attach them, which was to weld them “inside” of the frame. (fig. 52, p. 84.)

I named the bar stool WARP after the effect that the bent steel rods create. The structure isn’t only a visual effect, but it also makes the structure stronger. Could this structure be used also somewhere else? I wanted to continue exploring and started sketching a wall mounted shelf. I wanted to create a shelf that creates an art-like piece against the wall and also creates a border around the items placed upon the shelf. WARP shelf is a two-level wall mounted shelf that is attached to the wall with four screws. The production would also be rather simple when the smaller rods are welded to the sides of the Ø10mm frame. Then they are cut to the right length and sanded. The bending of the shelves is done after the welding. (fig. 54 & fig. 55, p. 86 – 87.)

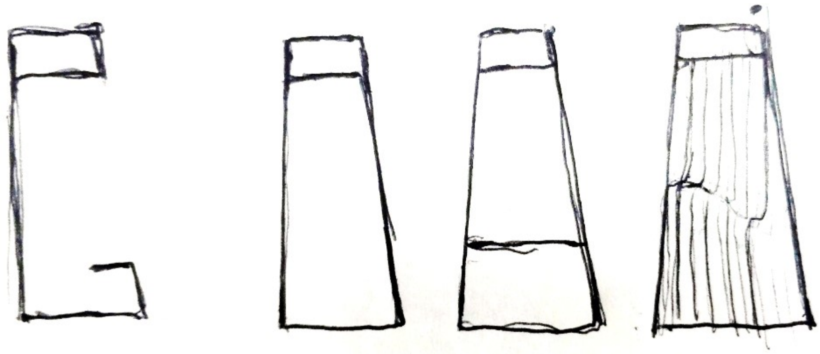


Figure 51 *First sketches.*

Figure 52 *Making the* WARP *stool.*

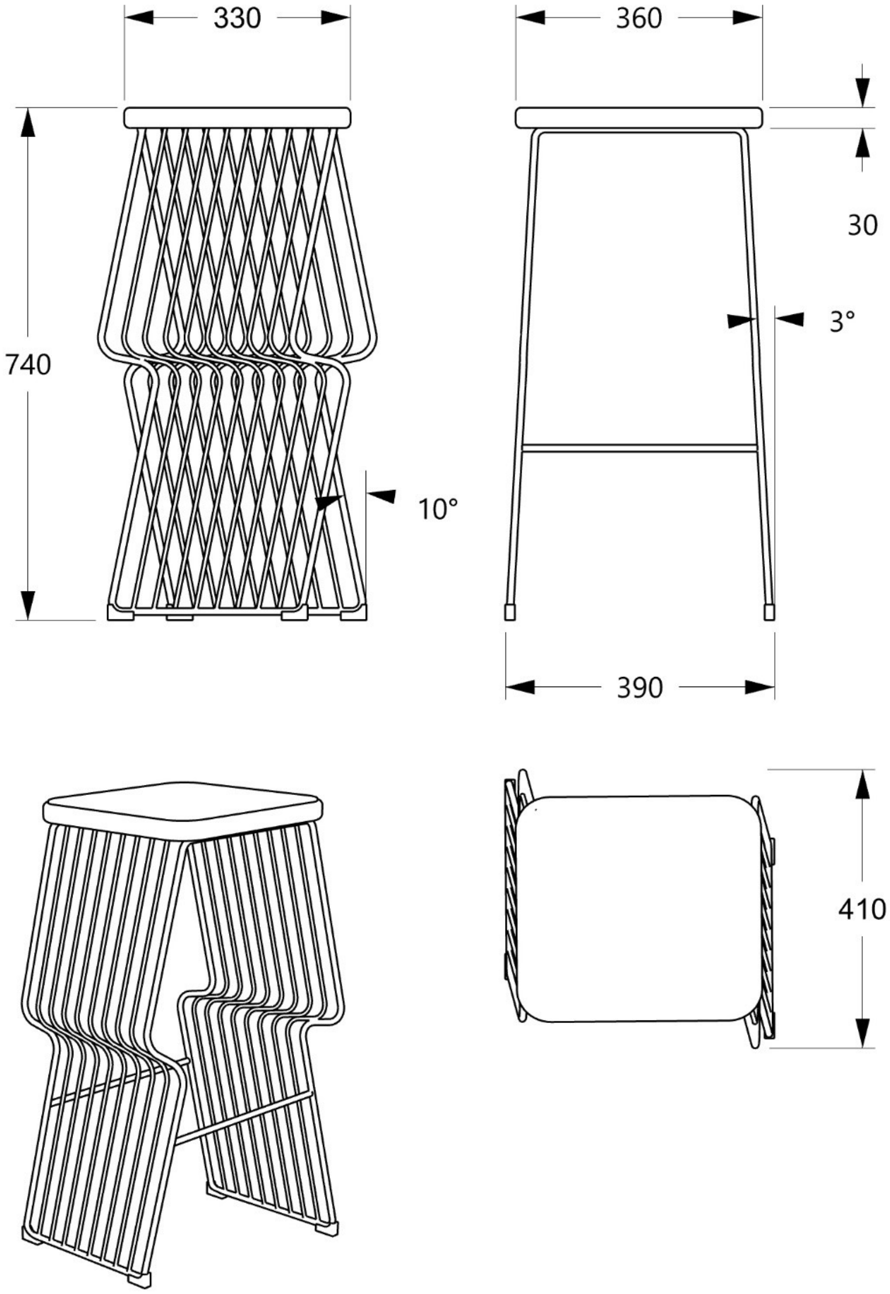


Figure 53 *Main measurements (image not in scale).*

Figure 54

The purpose of the existence of the WARP *stool is to prove that not everything in this world is how it might first appear. The way the steel structure is bent makes the appearance vary from different angles.*

Figure 55 WARP *shelves*

4. SUMMARY

In autumn of 2016 I visited Yaoi Kusama's retrospective exhibition, *In Infinity,* in Moderna Museet in Stockholm. I had just started to work on this thesis, but then I knew I was on the right track. The impact of her work for me was similar to Vasarely's exhibition mentioned in the foreword, p. 5, but this time I also realized the wider interest to these themes. The itinerant exhibition has gained huge popularity and a lot of attention in all over the world.

In autumn 2017, I took part in a lecture about trends of the year for 2018 organized by *Habitare*, Finland's largest interior decoration and design event. The lecture *Roots - Pintaa syvemmälle* was held by Mia Dillemuth and Antti Rimminen (31.10.2018) both from *Around*, a fashion journal dedicated to trends and signals. Among many other matters, they emphasized the importance of our senses, tricking of them and creating *mind altering design*. They also mentioned oddness, psychedelia and quality as already existing and continuing or emerging trends in design and interior design. I don't want to be the kind of designer who follows trends, but I do agree that trends tell something about the world and time we're living in. I am convinced that I have designed something that is very *now* and desirable not only for me but for the wider public.

I must admit that, despite my best efforts, I partially failed in the explorative prototyping process, as I got too excited by the results and couldn't stay within my pre-determined set timeframe. But I am altogether very satisfied with the theoretical basis and the outcome of my research. If I were to critique my work at this stage, I would acknowledge that I am aware that the bar stool isn't sturdy enough and would not pass the strictest of industrial stability tests. But as a prototype and the beginning of the product development, I am very pleased with the outcome.

I have now worked with optical illusions for around five years. I know a lot about them, and I have plenty of ideas about how to use them in my future work. They still are truly my passion, but I feel like I have to do something else next in my design work to be able to remain a versatile designer.

This is not a text that presents all the possible optical illusions and their applications. There are many more examples and possible ways to do similar work. I could have experimented with hundreds of illusions more, but like in most cases, time is a designer's worst enemy and the work needs to come to an end. In this case, this work ends here.

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APPENDICES

METHODOLOGICAL PHASE	SECTION	INTEREST OF KNOWLEDGE	DATA (WHAT)	METHOD (HOW)	APPROACH
1) theoretical basis	1. FOREWORD	technical	Knowledge about: - terminology	Literature review	descriptive
	2. INTERNAL REPRESENTATIONS OF THE EXTERNAL WORLD		Knowledge about: - optical illusions - op art - benefits/ role/ meaning of optical illusions and perception (reality and delusions) - the science and mathematics that cause optical illusions - behavior of the eye and brain	Inspiring projects / people / interviws/ images / product / exhibitions…	
	3) FROM TWO-DIMENTIONAL TO THREE-DIMENTIONAL / 3.1		- existing designs		
2) explorative prototyping	3.2 3.2.1. 3.2.2.	technical & intuitive	Material (understanding) for the actual design work concrete mockups, drawings, modelings, paintings, tests..	explorative prototyping	explorative (open ended, experimental investigation of the phenomenon)
3) creating	3.2.3.	intuitive	A piece or a series of furniture /object that contains a strong understanding of optical illusion in the structure	own artistic design work and documenting it	explorative / explanatory

Appendix 1

The interests of knowledge, approach, used methods and the pursued data in the three different methodological phases

Appendix 2

Tärnö chair by IKEA, Image retrieved 25.4.2019 from:
https://www.ikea.com/us/en/catalog/products/90095428/

Appendix 3

Liquorice chairs, Henri Judin 2017.
Image retrieved 25.4.2019 from: https://henrijudin.com/Liquorice-chairs